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to the

Merced Canyon

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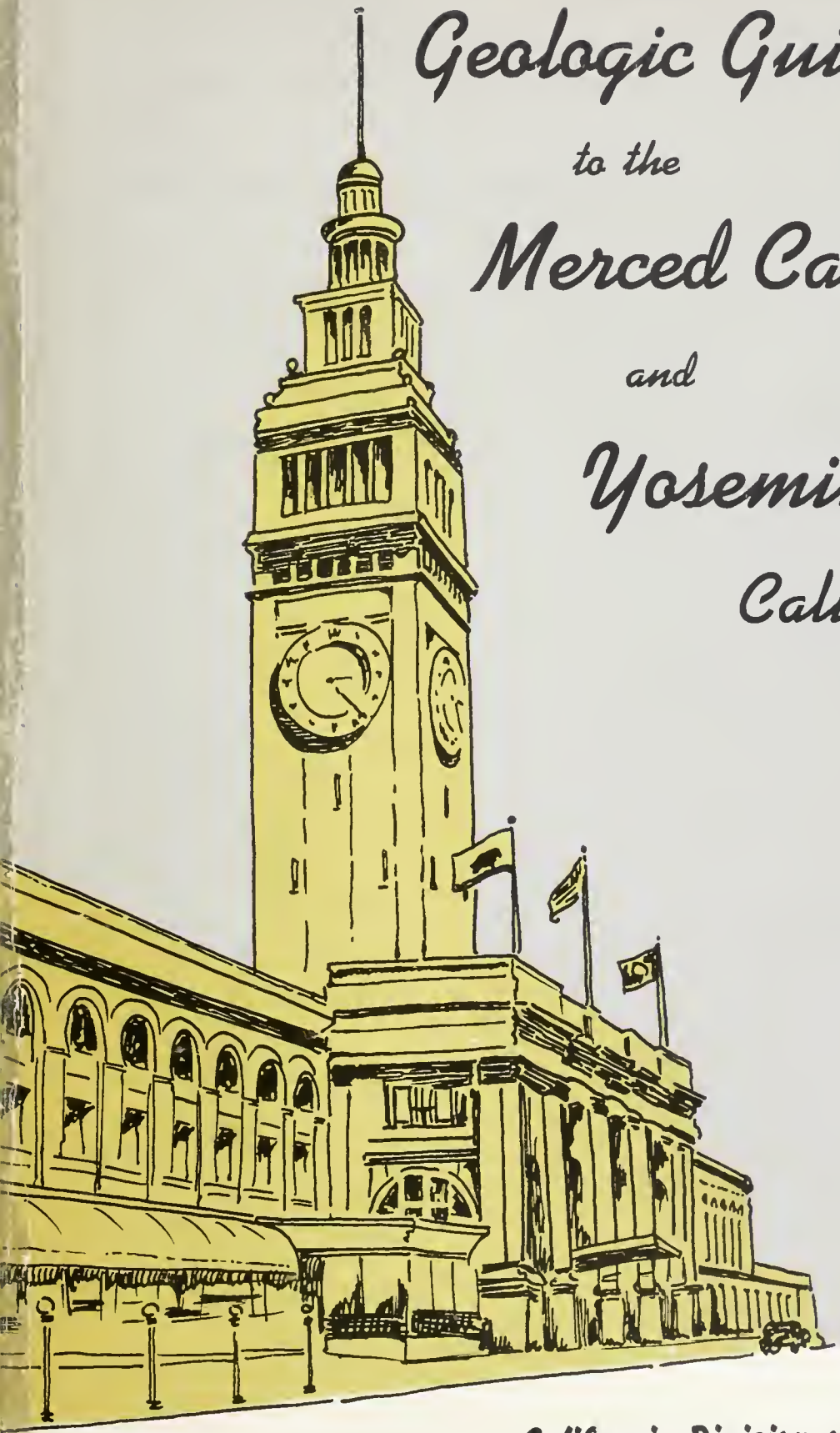

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California Division of Mines and Geology

Bulletin 182

GEOLOGIC GUIDE TO THE MERCED CANYON AND YOSEMITE VALLEY, CALIFORNIA

With Road Logs From Hayward Through Yosemite Valley, Via Tracy, Patterson, Turlock, and Merced Falls

Bulletin 182
CALIFORNIA DIVISION OF MINES AND GEOLOGY
FERRY BUILDING, SAN FRANCISCO, 1962

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DEPARTMENT OF CONSERVATION
DeWITT NELSON, *Director*

DIVISION OF MINES AND GEOLOGY
IAN CAMPBELL, *State Geologist*

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in conjunction with the

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at

SAN FRANCISCO, CALIFORNIA

March 26-29, 1962

GORDON B. OAKESHOTT, *General Chairman*

NOEL H. STEARN, *General Vice-Chairman*

WILLIAM F. BARBAT, *Vice-Chairman for SEPM*

CONTRIBUTING AGENCIES

California Division of Mines and Geology
United States Geological Survey
University of California

CONTRIBUTING AUTHORS

Rodney J. Arkley
Frank C. Calkins
Lorin D. Clark
Frederic R. Kelley
Dallas L. Peck
Holly C. Wagner
Clyde Wahrhaftig

FIELD TRIP COMMITTEE

PARKE D. SNAVELY, JR., *Chairman*

JACK E. SCHOELLHAMER, *Vice-Chairman*

YOSEMITE VALLEY TRIP

Frank C. Calkins
Larin D. Clark
Frederic R. Kelley
Max B. Payne
Dallas L. Peck
Holly C. Wagner
Clyde Wahrhaftig

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Harold Rader
K. A. Wright

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LETTER OF TRANSMITTAL

To: Edmund G. Brown
Governor of the State of California

Dear Sir:

I have the honor to transmit herewith Bulletin 182, *Geologic guide to the Merced Canyon and Yosemite Valley, California*, a collection of four significant papers on the geology and soils of this great park area, and a series of road logs across the Coast Ranges and San Joaquin Valley into the Yosemite. This bulletin is the result of cooperation between the State Division of Mines and Geology and the U.S. Geological Survey and was prepared as the second of two guidebooks whose publication coincides with the Annual Convention of the American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists.

Description of the geologic features and the road logs extends across the Tracy and Vernalis gas fields of the northern San Joaquin Valley and into the Yosemite Valley via the Sierra Nevada foothills across the southern end of the famed Mother Lode. At the western gateway to the Valley lie historically great gold mines and the barite deposits of El Portal. Photographs have been selected to do full justice to the beauty and grandeur of the Yosemite, our most-visited national park.

Respectfully submitted,

DeWitt Nelson, *Director*
Department of Conservation

January 11, 1962

PREFACE

In performance of its function as the State's public information bureau on geology, mineral resources, and mineral industries, the Division of Mines and Geology assists the petroleum industry, responsible for two-thirds of California's annual mineral production, in the general area of exploration. This it does by detailed geologic mapping of selected areas and by reconnaissance of large areas on the 1:250,000 scale, and by publication of several series of geologic maps and reports, many of which are useful to petroleum exploration. These are: *Mineral Information Service*, a semi-popular monthly pamphlet; *Annual Report* of the State Geologist, Chief of the Division of Mines and Geology; the *Bulletin* series, on the geology and mineral resources of quadrangles, geologic guides to significant regions, or on statewide commodity surveys; the *Special Report* series on shorter or more localized subjects; the new *County Report* series on the mines, mineral resources, and geology of counties; and the *State Geologic Map*, issued as colored, lithographed, 1:250,000-scale geologic map sheets, each 1 degree in latitude by 2 degrees in longitude.

In planning field trips and a guidebook which would be most interesting and of greatest benefit to the petroleum profession, as well as to the people of California, the committees felt that the greatest effort should be directed toward presentation of geologic features of northern California of direct economic importance to the petroleum industry; and also that our unique scenic geological attractions should not be neglected. The first condition has been satisfied by Bulletin 181, *Geologic guide to the gas and oil fields of northern California;* the second we hope to meet with this publication, Bulletin 182, *Geologic guide to the Merced Canyon and Yosemite Valley, California.* The latter book is the result of cooperation between the U.S. Geological Survey, the University of California, and the State Division of Mines and Geology. It consists of four papers by Survey and University authors on the metamorphic and granitic rocks of the western Sierra Nevada, the geomorphology of the area, and on soils of the San Joaquin Valley along the Merced River, followed by continuous road logs from Hayward across the Coast Ranges and northern San Joaquin Valley and through the Yosemite Valley. Route of the trip is by way of Altamont Pass across the Diablo Range and close to the Tracy and Vernalis gas fields of the northern San Joaquin Valley. Those interested in more geology relating to this area and the occurrence of gas are referred to the section *Northern San Joaquin Valley*, in Bulletin 181, which contains *Vernalis gas field*, by Charles F. Manlove, *Cretaceous geology of the Pacheco Pass area*, by Frederick O. Schilling, and *Type Panoche group (Upper Cretaceous) and overlying Moreno and Tertiary strata on the west side of the San Joaquin Valley*, by Max B. Payne. Bulletins 181 and 182, together, constitute a unit which should give the geologist an adequate geologic background for understanding the occurrence of gas and oil in northern California.

Gordon B. Oakeshott
General Chairman, AAPG-SEPM
Convention, 1962
and Deputy Chief, Division of
Mines and Geology.

San Francisco
January 11, 1962

Frontispiece. Yosemite winter storm, by Ansel Adams. From *Portfolio Three* (Yosemite Volley), published by the Sierra Club, San Francisco, 1959.

Part I—GEOLOGIC GUIDE TO THE MERCED CANYON AND YOSEMITE VALLEY, CALIFORNIA

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PLATES

Plate 1. Geologic map and section of the southern part of the western Sierra Nevada metamorphic belt ..... In pocket

Frontispiece, Part I, opposite. Winter, Yosemite Valley. Half Dome and the Merced River. Photo by Ansel Adams.

SUMMARY OF THE PRE-TERTIARY GEOLOGY OF THE WESTERN SIERRA NEVADA METAMORPHIC BELT, CALIFORNIA *

By LORIN D. CLARK
U.S. Geological Survey, Menla Park, California

Plate 1, Geologic map and section of the southern part of the western Sierra Nevada metamorphic belt, accompanies this paper.

Metamorphic rocks of the western Sierra Nevada near the Merced River are of Jurassic and Paleozoic age. They are on the west limb of a faulted synclinorium, the central part of which is occupied by the Sierra Nevada batholith. Parts of the eastern limb are preserved in the eastern part of the Sierra Nevada and in the White and Inyo Mountains still farther east. The metamorphic rocks strike northwest, as reflected in the map pattern of lithologic units (pl. 1), and nearly everywhere dip steeply eastward or are vertical. The metamorphic rocks are divided into three structural blocks by the Melones and Bear Mountains fault zones (Clark, 1960). The structure within each block is generally homoclinal with younger beds to the east, but the gross distribution in the metamorphic belt as a whole has been reversed by fault movement, for the youngest metamorphic rocks are in the western fault block and the oldest in the eastern block. Dominant strike-slip movement along the Bear Mountains and Melones fault zones is suggested by steeply-plunging minor folds and b-lineations within the zones. The stratigraphic separation along the Melones fault zone near the Merced River is at least 10 miles, and the stratigraphic separation along the Bear Mountains fault zone farther north exceeds 3 miles. Because the dihedral angle between bedding and faults is small, the net slip along the fault zones must be much greater than the stratigraphic separations.

The Paleozoic rocks, which are entirely east of the Melones fault zone in the area of plate 1, are all included in the Calaveras formation. The lower part of the formation, exposed near Bagby, consists largely of phyllite derived from siltstone, but contains some interbedded tuff and graywacke and sparse lenticular limestone. These are overlain by metavolcanic rocks, derived mostly from coarse andesitic breccia but in part from pillow lava and tuff. From Briceburg northeastward to the large horseshoe bend in the Merced River, the Calaveras formation consists largely of black phyllite derived from siltstone [redacted] metachert, sparse limestone [redacted]t, intraformational conglom- [redacted] eastward the black phyllite persists, but metacherr constitutes a considerable part of the section, lenses of limestone and dolomite are larger and more abundant, and lenses of mafic metavolcanic rocks are common. The age of the Calaveras formation near the Merced River is based upon H. W. Turner's identification of *Fusulina*, which he considered to be of Carboniferous age, from a locality a few miles southwest of El Portal (1893, p. 309). No fossils other than crinoid debris have been found in the lower part of the formation. Because of shearing of parts of the Calaveras formation east of Briceburg, its thickness cannot be determined accurately, but it is almost certainly more than 25,000 feet, and it may be more than 50,000 feet thick.

Mesozoic rocks, consisting of complexly intertonguing metavolcanic and metasedimentary strata, constitute the central and western fault blocks and occur in the eastern fault block east of Bear Valley. The Mariposa, Consumnes, and Logtown Ridge are among the named formations. The metavolcanic rocks were derived chiefly from tuff and volcanic breccia of intermediate composition, but in part from basaltic lava, some with pillow structure, and in part from felsic lava and pyroclastic rocks. The metasedimentary [redacted]s were derived largely from [redacted] mixed-pebble metaconglom- [redacted]me sections. Metamorphosed [redacted] abundant locally. Both the [redacted] and volcanic rocks accumulated in deep water for graded beds are common in both tuff and graywacke throughout the region. Marine fossils found in both metavolcanic and metasedimentary rocks are of Late Jurassic (Callovian to Kimmeridgian) age. Everywhere in the western Sierra Nevada the Jurassic strata are truncated by faults or erosion—the section in the central fault block along the Merced River is nearly 18,000 feet thick and is among the thickest preserved.

* Publication authorized by the Director, U.S. Geological Survey.

Two groups of plutonic rocks intruded these metamorphic rocks during Late Jurassic time and one group in middle-Cretaceous time. The first was an ultramafic group, now represented mostly by serpentine, and the second a group ranging from diorite to granodiorite. In middle-Cretaceous time, according to radiometric data obtained by Curtis, Evernden, and Lipson (1958, p. 7-9), the Sierra Nevada batholith was intruded. Rocks of the batholith are described by F. C. Calkins and D. L. Peck elsewhere in this guidebook.

Uplift and perhaps gentle folding occurred in the Sierra Nevada region between about middle Permian and middle Jurassic time, but most of the deformation of both Paleozoic and Mesozoic strata occurred during Late Jurassic and possibly Early Cretaceous time. The synclinorium was formed in Late Jurassic time, before intrusion of the older series of granitic rocks, and resulted in the northwest strike and steep dip of Mesozoic and Paleozoic strata. Axes of folds formed during this deformation plunge northwest and southeast at angles of less than 30°. The second major deformation also began before emplacement of the older granitic rocks, but possibly continued into the Early Cretaceous. The major faults, pervasive shearing of the eastern block, and steeply plunging minor folds and lineations resulted from the second major deformation.

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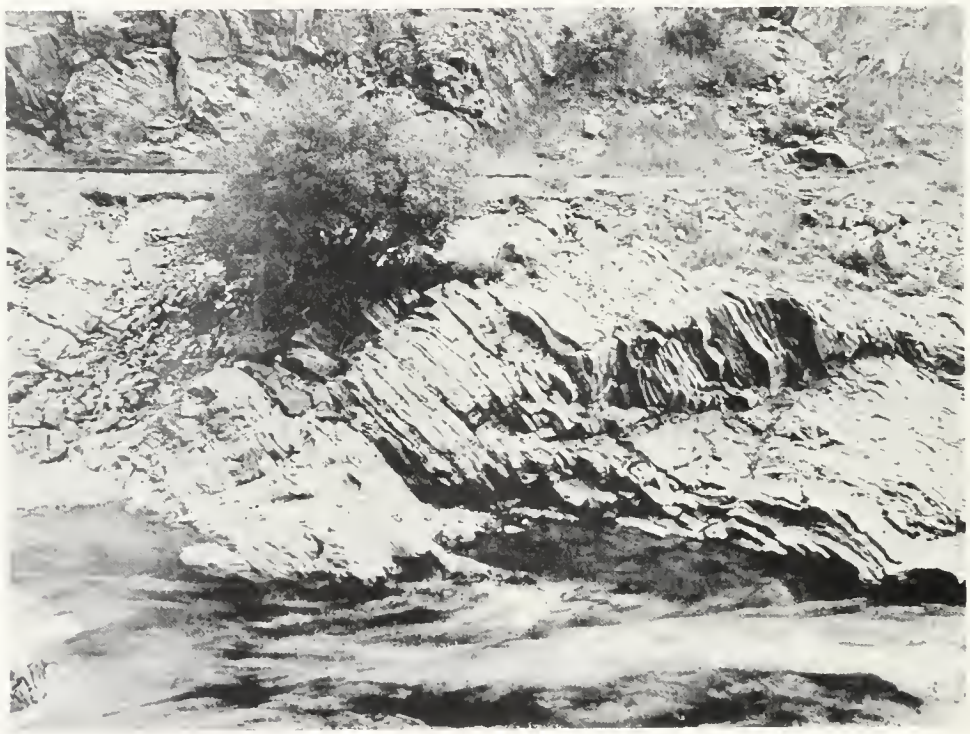

Photo 1. Interbedded metachert and black carbonaceous phyllite of the Calaveros formation of Paleozoic age near the Geologic Exhibit marker. These beds are little folded, but nearby are intricately folded strata. Photo by U.S. National Park Service.

GRANITIC ROCKS OF THE YOSEMITE VALLEY AREA, CALIFORNIA *

By FRANK C. CALKINS
U.S. Geological Survey, Menlo Park, California, and

DALLAS L. PECK
U.S. Geological Survey, Menlo Park, California

BRIEF HISTORY OF DISCOVERY AND GEOLOGIC INVESTIGATIONS

The Yosemite Valley was discovered by William Penn Abrams in 1849, but it first became well known when it was rediscovered in 1851 by the Mariposa Battalion, under the leadership of Major James D. Savage, while pursuing the Indian tribe called the "U-zu-ma-ti" (meaning "grizzly bear"), led by Chief Tenaya. The members of the Battalion gave the valley the name that they understood to be that of the tribe; the Indians themselves called it "Ahwahnee", meaning "deep, grassy valley". The valley achieved national fame through the writings of Dr. Lafeyette Bunnell, James Hutchings, John Muir, the Reverend Thomas Starr King, and others. In 1864 an area that included the Yosemite Valley and also the Mariposa Grove was set aside by the Federal Government as the Yosemite Grant; this area was administered by California until 1905, when it was included in the much larger Yosemite National Park, which had been established in 1890.

Geologic investigations in the Yosemite Valley region, most of which have been summarized by Matthes (1930, p. 4-7), were begun in the early 1860's by J. D. Whitney, State Geologist of California, who was assisted by Clarence King. Whitney (1868) and King (1874) concluded that the valley was formed by faulting so recent that the valley walls had not been greatly modified by subsequent erosion. In the late 1860's and later this view was challenged by W. P. Blake (1867), John Muir (his extensive bibliography was published in the Sierra Club Bull. vol. 10, p. 41-54, 1916, but see particularly Muir, 1874 and 1875), and Joseph LeConte (1873), who attributed the formation of the valley to glacial and stream erosion. The general extent of the Sierra Nevada composite batholith was described in the 19th century in geologic reports and folios by H. W. Turner, Waldemar Lindgren, and others, but detailed study of this vast intrusive complex is still going on and may continue for years to come. Near the turn of the century Turner began to map the geology of the Yosemite and Mount Lyell quadrangles, but was never able to complete this difficult assignment. Shortly before World War I, F. E. Matthes and F. C. Calkins began a highly detailed study of the physiography and bedrock geology of the Yosemite Valley area and a less detailed mapping of surrounding areas in the Sierra Nevada (1930), but the complex bedrock geology of the valley has not even yet been fully mapped. Ernst Cloos (1936) plotted structural features in the granitic rocks of the Yosemite region, Blackwelder (1931, p. 907-909; 1939) related the glacial stages to those of the eastern flank of the Sierra Nevada; and Curtis and others (1958) obtained potassium-argon ages of some of the granitic rocks.

SIERRA NEVADA BATHOLITH

The rocks in which the Yosemite Valley was carved belong almost wholly to the great Sierra Nevada composite batholith, which extends continuously along the range for about 400 miles and has a maximum breadth of about 100 miles. The rocks of this batholith were intruded into sedimentary and volcanic rocks of early Paleozoic to Mesozoic (Late Jurassic) age. As shown by Bateman and others (in press) it was emplaced along the axis of a synclinorium in those layered rocks. The prebatholithic rocks are not represented in the Yosemite Valley except by a few small masses not visible from the valley floor, but the roads from the west pass through them for many miles on the way to El Portal (see description by Clark in this guidebook), and they are widely exposed on the east side of the batholith along the crest of the range. Rinehart and others, (1959), found that pre-batholithic rocks they mapped in the Devils Postpile and Mount Morrison quadrangles have a total thickness of about 60,000 feet. The lower half of the stratigraphic column there consists of sparsely fossiliferous Ordovician to Permian(?) hornfels, metamorphosed calcareous sandstone, slate, and marble; these are overlain conformably by about the same thickness of metamorphosed pyroclastics and lavas, with a few minor interbeds of calcareous and tuffaceous rocks which have yielded fossils of Early Jurassic age.

* Publication authorized by the Director, U.S. Geological Survey.

FIGURE 1. Generalized geologic map of the Yosemite Valley area, California.

It needs to be emphasized that the Sierra Nevada batholith is *composite*. Some people fail to realize how complex it is, and what a long and eventful history it has had. At least seven irregular intrusive bodies such as are commonly called stocks, are exposed in the walls of Yosemite Valley and the Merced Gorge, and measurements of potassium-argon ratios indicate that the oldest and youngest of these differ in age by about 12 million years, though all of them were intruded in Cretaceous time. The stocks are cut, moreover, by dikes and irregular sheets of at least half a dozen other kinds of rocks—not counting pegmatites and aplites. On the nearby uplands, moreover, within the area drained by tributaries of the Merced and the headwaters of the Tuolumne, one can see exposures of many other intrusive bodies, large and small. If this area gives us anything like a fair sample, the Sierra Nevada batholith was formed by scores, if not hundreds, of distinct intrusions, and the making of it may have taken something like 15,000,000 years.

Brief descriptions are given below of the intrusive rocks exposed in the valley and the gorge, and also of two others that are closely related to the rock forming the falls of the eastern part of the valley, but that could not be reached without going eastward to the Tuolumne Meadows. The distribution of the major intrusive rock units in the Yosemite Valley area is roughly shown in figure 1.

AGE RELATIONS OF THE INTRUSIVE ROCKS

Principal Groups

The rocks that form relatively large bodies exposed in the Yosemite Valley and in line with it to the east and west may be assigned to two series, the western and the Tuolumne intrusive series. The western intrusive series, which is the older, forms the walls of the western half of the valley, and of the canyon of the Merced down to El Portal. The younger rocks of the Tuolumne intrusive series are exposed in the eastern half of the Yosemite Valley and in the high country still farther east, which is drained in part by the Tuolumne River. The rocks of both series are cut by aplites and pegmatites, which will not be described and which are not included in the group to be considered next.

Generally intermediate in age and position between the intrusive bodies, of large to moderate size, that have been assigned to the western and Tuolumne series, there are a great many dikes, sills, and small irregular bodies that do not clearly belong to either series. All of them are probably younger than any rock of the western series. None is now known to be younger than any rock of the Tuolumne intrusive series, but one or two of them could be. Because of these uncertainties, combined with the fact that no potassium-argon ratios have been determined for any of these minor intrusive bodies it seems expedient to put them in a separate group. In the petrographic summary they are placed between the western and Tuolumne series. They are for the most part at least intermediate in age between the two, and are mainly exposed in the middle part of the valley.

The extreme complexity of the intrusive pattern in the Cathedral Rocks and El Capitan suggests—though it does not prove—that a local subsidence occurred in the area crossed by the middle part of the valley, perhaps shortly after the intrusion of the western series was completed. Such a mechanism could help to account for the generally flat-lying attitude of the intrusive bodies of Bridalveil granite; withdrawal of support would have tended to open approximately horizontal fissures into which magmas would be injected from a pluton that has not been identified and may not be exposed. But subsidence would also have opened steep fissures to be filled by dikes. There is evidence, also, that sulfide-bearing solutions arose along some of the steep fissures, for here, and nowhere else in the Yosemite Valley area, some of the rocks contain a little pyrite, the weathering of which produced iron oxides that have locally imparted a red color to the outcrops, especially on the southwestern slopes of the Cathedral Rocks. In a few places, moreover, a very little molybdenite has been found.

Western Intrusive Series

The sequence of intrusion within the western series is not fully known. Field relations prove that the Taft granite is its youngest member, that it was preceded by El Capitan granite, and that El Capitan was preceded by both the diorite of the Rockslides and the granite of Arch Rock. No field evidence had been obtained, however, regarding the relative ages of the granite of Arch Rock, the above-mentioned diorite, and the granodiorite of The Gateway. Potassium-argon ratios obtained by Curtis and others (1958) indicate that the granite of Arch Rock is older than the granodiorite of The Gateway, and the latter rock older than El Capitan granite. This dating of the granite of Arch Rock seems questionable because it does not accord with the usual order in an intrusive series—that of increasing silica content. It is nevertheless provisionally accepted in the petrographic summary, in which the diorite of the Rockslides is assumed—again provisionally—to be the oldest member of the series.

Minor Intrusive Bodies

The order in which the small bodies were intruded is not fully known and may never be completely worked out. We do not even know how many different kinds of rock they consist of, and only a few are described herein, in an order that represents the best guess we can make regarding their relative age. The one that occupies the largest areas on the map (fig. 1) is the Bridalveil granite. This cuts nearly all of several rocks with which it is in contact, but although it is widely exposed on the south side of the valley, especially in the Cathedral Rocks and along Bridalveil Creek, it has not been positively identified on the north side. The youngset of all these rocks may be the diorite forming the "Map of North America," on the face of El Capitan, which cuts across a dike, sloping upward toward the east, of a gray rock that is probably Leaning Tower quartz monzonite.

This diorite does not differ much from the diorite of the Rockslides except in being generally finer grained. As we have provisionally regarded the older diorite as the oldest member of the western series, the younger diorite is possibly to be regarded as the oldest member of the Tuolumne intrusive series; for the present, however, it is not described as such.

Tuolumne Intrusive Series

After having had to confess how much we don't know about the order of intrusion in the western series and the minor intrusive bodies, it is a relief to come to the Tuolumne intrusive series. For here the sequence of intrusion is clearly shown by field relations, and confirmed by measurements of potassium-argon ratios in all four members. The order of intrusion appears, also, to be that of increasing silica content, which is commonly regarded as the normal order; this however is as yet uncertain because of a lack of analyses. The outcrops of the four members, moreover, are roughly concentric in the central part of the area occupied by the series, the latest member being in the center. Because this series is so definitely a unit, we briefly describe it as a whole, even though only its two oldest and outermost members—the Sentinel granodiorite and the Half Dome quartz monzonite—are exposed in the Yosemite Valley. In the Yosemite Valley one cannot even see the porphyritic facies of the Half Dome quartz monzonite into which the non-porphyritic facies, exposed around the head of the Yosemite Valley and in Half Dome itself, grades near Tenaya Lake. The porphyritic Half Dome quartz monzonite is cut in that vicinity by dikes of the Cathedral Peak granite, and one can see from the valley floor, in the cliff west of the Royal Arches, flat-lying tongues of streaky Half Dome quartz monzonite extending into the Sentinel granodiorite. A little farther west, in the Castle Cliffs, the granodiorite is intruded into the El Capitan granite in an extremely complex fashion, forming a pattern that has to be greatly generalized even at a scale of 1:24,000 and could merely be suggested in figure 1. Little of this pattern can be seen from the floor of the Yosemite Valley; it is better exposed along Yosemite Creek above its falls and on the upland south of Glacier Point.

CHARACTER OF THE INTRUSIVE ROCKS

The following short descriptions do not aim to do much more than help those interested to distinguish the principal rocks from one another. The rocks described by Calkins (1930, p. 120-129), are here called by the names used in that publication. These names are largely based on megascopic rather than microscopic features, and some of them do not depend as much as some petrographers would like upon relative abundance of potassium feldspar and plagioclase. The dominant rock of El Capitan, for example, was called by H. W. Turner (1900, p. 304, 308) El Capitan granite, and that name has come into general use. It is based on the fact that the dominant facies of the rock contains abundant and conspicuous potassium feldspar and quartz, and only a small proportion of its one ferromagnesian mineral, biotite. Roughly quantitative measurements of mineral composition indicate, however, that the dominant rock of this intrusive mass is a quartz monzonite if the feldspar ratio is made the criterion, though it contains more quartz than most quartz monzonites.

The rocks are listed in what is regarded as their most probable order of age—the oldest first. Whenever the age of a rock has been estimated from the potassium-argon ratio by Curtis and others (1958, p. 7), the result, in millions of years, is given at the end of the description as "K/Ar age——m.y."

Rocks of the Western Intrusive Series

Diorite of the Rockslides. General color very dark greenish-gray. Texture varies from very coarse to medium-grained. Chief minerals plagioclase and hornblende, the latter being the more conspicuous; most specimens also contain subordinate quartz, potassium feldspar, and biotite, and some contain a little augite. The rock may be in part a metagabbro.

Granite of Arch Rock. Medium-light-gray, medium-grained, non-porphyritic. Plagioclase predominates over potassium feldspar, which is generally poikilitic, as can be seen by reflections from cleavage faces. Quartz moderately abundant. In most of the rock the only ferromagnesian mineral is biotite (subhedral to anhedral), but a little hornblende is present in some places.

K/Ar age 95.3 m.y.

Granodiorite (or Quartz Diorite) of The Gateway. Dark-gray, medium-grained. Potassium feldspar subordinate; some of the rock does not contain any. Biotite is fairly abundant, hornblende less abundant but everywhere present.

K/Ar age 92.9 m.y.

El Capitan Granite. Light-gray, medium-coarse-grained. Some is vaguely porphyritic, with phenocrysts of potassium feldspar. Plagioclase is more abundant but in smaller grains. Quartz is conspicuous. Biotite, in moderate quantity, is the only ferromagnesian mineral, though a little hornblende may occur in marginal facies.

K/Ar age 92.2 m.y.

Taft Granite. Very light gray, medium-grained. Typical facies finer-grained and more uniform than El Capitan granite and not porphyritic, but a rock that may be a porphyritic facies of the Taft, exposed near the east portal of the Wawona tunnel, contains phenocrysts of potassium feldspar. Plagioclase, potassium feldspar, and quartz about equally abundant; biotite scarce.

Rocks of Minor Intrusive Bodies

Leaning Tower Quartz Monzonite. Color medium-gray; texture medium-grained granular. Contains biotite and less hornblende; these are largely in clusters, about 10 mm in maximum diameter, which give the rock a characteristic speckled appearance.

Bridalveil Granite. Medium-gray; the fresh rock has a slightly bluish tinge. Fine-grained, granular. Biotite

moderately abundant, in small, evenly distributed flakes which give the rock a "pepper-and-salt" appearance.

Quartz-Mica Diorite. Medium-dark gray, medium-fine-grained, granular. All consists mainly of plagioclase, quartz, and biotite; most contains subordinate potassium feldspar and some contains a little hornblende. Not shown in figure 1.

Diorite of the "Map of North America". Similar to the diorite of the Rockslides but finer-grained. Represented by the same pattern as the diorite of the Rockslides.

Rocks of the Tuolumne Intrusive Series

Sentinel Granodiorite. Generally medium-dark gray and medium-grained granular, but varies rather widely in both color and texture. Near contacts with El Capitan granite the rock tends to be darker than elsewhere and more or less foliated. Plagioclase predominates over potassium feldspar; quartz is inconspicuous. Biotite is fairly abundant and hornblende only a little less so; both are in irregular grains tending to cluster together.

K/Ar age 86.4 m.y.

Half Dome Quartz Monzonite. Lighter-colored and more uniform in both color and texture than the Sentinel granodiorite. Its potassium feldspar, though only about half as abundant as plagioclase, is more conspicuous because in larger crystals. In a porphyritic facies exposed near Lake Tenaya—not seen from the Yosemite Valley—there are numerous phenocrysts of potassium feldspar. Biotite and hornblende are less abundant than in the Sentinel granodiorite, and both tend to form discrete, fairly regular crystals.

K/Ar age 84.1 m.y.

Cathedral Peak Granite. A light-gray rock, characterized by numerous large phenocrysts of potassium feldspar (some as much as 2 inches long) in a medium-grained granular groundmass consisting of both feldspars, much quartz, a moderate amount of biotite, and a little hornblende. Not exposed in the area of figure 1, but boulders of this rock in the moraines of Yosemite Valley are among the evidences for glaciation of the Sierra Nevada.

K/Ar age 83.7 m.y.

Johnson Granite Porphyry. A porphyritic rock, lighter-colored and finer-grained than the Cathedral Peak granite; contains a little biotite but no hornblende. Not exposed in the Yosemite Valley.

RELATION OF TOPOGRAPHY TO ROCKS AND STRUCTURE

The major features of the Yosemite Valley are due to erosion by streams and glaciers, whose handiwork was described at length in Matthes's classic paper (1930) and has been summarized in another section of this guidebook. But sculptural detail, in this area as in any other, depends to a large extent on the material that erosional agencies had to deal with—on what rocks they encountered as they worked downward. If the bedrock in the upper-middle part of the Merced basin had been of uniform composition and structure, erosion would never have produced a Yosemite Valley. One reason for the astonishing variety of sculpture that causes the Yosemite to stand unrivalled in the Sierra Nevada or anywhere else for the magnificence of its falls, cliffs, and domes, all displayed within a distance of about 7 miles, is the varied nature of the rocks in which it was carved. The differences that matter in this regard are differences in susceptibility to erosion. These are not due mainly to differences in hardness, which are not very great. There are greater differences in resistance to weathering, but these again would not have had very much effect if the rocks had all been jointed to the same extent. The great contrasts in topographic expression arise from the different degrees to which the various rocks have been jointed. Broadly speaking, the more siliceous rocks of the Yosemite Valley are less jointed than the less siliceous rocks. It has been thought, however, that in other areas texture rather than composition is the determining factor, the finer-grained rocks being the more closely jointed. The degree of jointing in the various intrusive rocks may therefore be the resultant effect of both factors in combination. El Capitan, whose southeast face is one of the highest unbroken cliffs in the world, consists chiefly of two of the most siliceous rocks that form large intrusive bodies in this area—namely El Capitan and Taft granites—and these determine its character even though they are cut by many small bodies of less siliceous rocks. The Cathedral Rocks and the Leaning Tower also probably stand out as they do because, though of extremely complicated makeup, they consist mainly of siliceous rocks. El Capitan granite is one of the most abundant materials in them, and the minor intrusive bodies here consist mainly of Bridalveil granite. Half Dome, the greatest monolith of all, and also the other prominent domes overlooking the eastern part of the valley, consist of the Half Dome quartz monzonite. This rock, judging from its mineral composition, appears to be a little less siliceous than El Capitan granite, but it is not cut by any rocks that are less siliceous, and this fact may help to account for its almost complete lack of joints. It is indeed cut by many narrow dikes of pegmatite and aplite, but these are more siliceous and even more resistant than the dominant rock, so that great numbers of them stand out in relief on the southern slope of Half Dome.

The Half Dome quartz monzonite is mainly in huge masses almost free from joints, and these have disintegrated for the most part by exfoliation, which occurs here on a grand scale. That is why this rock forms nearly all the domes; the single exception is Sentinel Dome, which consists of El Capitan granite. The Royal Arches reveal a cross section of exfoliation cracks in the quartz monzonite that are too far below the surface to form the tops of domes.

The rock nearest in composition to the Half Dome quartz monzonite—on the less siliceous side—is the Sentinel granodiorite, which is cut by numerous joints. The lower part of the cliff east of Glacier Point consists of

Phato 1. Cliff face below Glacier Paint, developed olang vertical jaints that trend almost due east.

unjointed Half Dome quartz monzonite, but this is overlain, on an intrusive contact sloping gently westward, by the granodiorite, which is considerably jointed; in fact the eye can trace the contact quite closely, from a viewpoint near the Ahwahnee Hotel, by noting this difference in structure. Many of the joints in the granodiorite strike about east-northeast and are nearly vertical; joints of this character have mainly determined the form of Sentinel Rock. The sheer cliff below Glacier is developed along vertical joints that trend almost due east. In the zone where there are complex intrusive relations between this granodiorite and El Capitan granite, the amount of jointing largely depends on which rock is the more abundant.

The least siliceous of the principal intrusive rocks is the diorite of the Rockslides, and although rather coarse-grained on the average it is by far the most closely jointed. For this reason it is exposed in only one large area, above the lower part of the Big Oak Flat Road, where it is cut by countless irregular joints, both steep and flat-lying; many of the flat ones are injected with sheets of light-colored intrusive rock. The diorite is held up here by a backing of Taft granite, which forms the upland surface immediately to the north. Turtleback Dome and Elephant Rock, south of the river, consist mainly of El Capitan granite.

The slope on the west side of the Merced Gorge consists mainly of the granite of Arch Rock. This is intermediate in composition between El Capitan granite and the diorite of the Rockslides, and it is likewise intermediate between them in the character of its jointing, though in both respects it resembles El Capitan granite more closely than it does the diorite. It is here cut by fairly numerous joints, most of which strike northeastward and are nearly vertical but somewhat irregular.

The large taluses on the sides of the Yosemite Valley contribute greatly to the variety of its sculpture, because they present so striking a contrast with the cliffs and "points" in which the bedrock extends nearly to the valley floor. There is reason to believe that the taluses are largely underlain by rocks that are closely jointed, so that their surfaces receded more rapidly than those of rocks containing few joints. The moderately large talus around the mouth of Indian Canyon is presumably underlain in large part by Sentinel granodiorite. The bedrock under the three largest taluses—the Rockslides and the taluses east and west of Bridalveil Canyon—is probably made up in considerable part of diorite. The Rockslides are flanked on the west by the largest exposures of the older diorite, and it seems likely that their eastern part covers an area in which the diorite receded all the way northward to its contact with El Capitan granite. Diorite is exposed in many places around the borders of the taluses on the south side of the valley east and west of Bridalveil Canyon; some of it can be seen near the east portal of the Wawona Tunnel.

One of the strangest features of the Yosemite Valley's topography is the manner in which the lower part of Bridalveil Canyon projects beyond the general course of the valley's southern wall. Bridalveil Fall springs from the end of what might almost be likened to a gigantic flume—though a very lop-sided one, since the Cathedral Rocks, on its northeast side, are of much greater bulk than the Leaning Tower, on its southwest side. This abnormal relation of relief to drainage appears to be partly explainable on the hypothesis that the rocks along Bridalveil Creek are much more siliceous, on the whole, than those underlying the great aprons of talus to the east and west.

So much for the topographic features whose character expresses jointing or the lack of it. But some notches and other depressions were eroded along more persistent fractures that may somewhat arbitrarily be distinguished as fissures.[1] Fissures, and fissure zones, cut across all kinds of rocks, even those in which there are few joints. They were doubtless formed by local concentration of strain, and there was probably some movement along them, though none have been shown to be large faults. Since many of the features due to fissuring were well described by Matthes (1930, p. 111-114) only a few of the more important will be noted here.

The west side of El Capitan is bounded by a north-south fissure zone in the lower part of which there is a basic dike, and the next main drainage way must have been eroded along another fissure zone that strikes northeastward. The middle Cathedral Rock is separated from the others by deep notches eroded along steep fissures that also strike about northeast, and the Cathedral Spires are probably bounded by vertical fissures. The Three Brothers, two miles northeast of El Capitan, which consist mainly of El Capitan granite, are separated from one another by two fissures, or master joints, that dip about 45° W.

The great monolithic mass of Half Dome itself is bounded on the northwest by a smooth, nearly vertical 2,000-foot cliff that must form the wall of a fissure, presumably the southeasternmost in a fissure zone that determined the course of Tenaya Creek. The Half Dome quartz monzonite is also cut by at least one gently dipping fissure that slants downward to the north in the lower part of the southwest face of Liberty Cap.

Steep fissures probably determined the location of many of the cliffs bordering the Yosemite Valley. The valley itself may have been eroded along a complex fissure zone which is now mostly concealed by alluvium; the two fissures that separate the Cathedral Rocks from one another may belong to this zone.

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[1] On the 1:24,000 topographic map of the Yosemite Valley, the word "Fissures" is printed a little southeast of "Taft Point", to designate a small group of notches along joints of northeasterly strike where they cross the brink of a steep cliff. These are shown by the contours on that large-scale map, but could not be shown on the small scale of figure 1. The word "Fissures" is used on the map in a somewhat different sense than the one defined above—to designate joint-cracks widened by erosion. Many joints of the same system as those in the Fissures can be seen on the slope across the gulch to the northeast, but there they are expressed only by shallow cracks.

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THE GEOLOGY, GEOMORPHOLOGY, AND SOILS OF THE SAN JOAQUIN VALLEY IN THE VICINITY OF THE MERCED RIVER, CALIFORNIA

By RODNEY J. ARKLEY
Lecturer and Specialist in the Agricultural Experiment Station
Department of Soils and Plant Nutrition
University of California, Berkeley, California

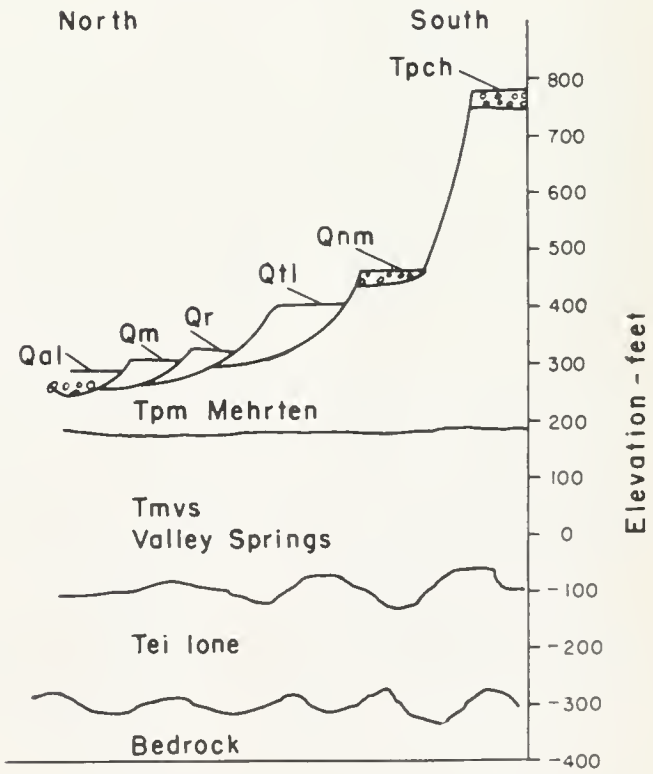
The Merced River emerges from a V-shaped gorge through the Sierra Nevada foothills into the San Joaquin Valley at the ghost town of Merced Falls, 30 miles east of Turlock. From this point it flows west-southwest for a distance of 40 miles, where it joins the northwestward-flowing San Joaquin River. On either side of the river is a series of geomorphic surfaces rising in steps to the north and south almost 500 feet above the river (figs. 1, 3). The two oldest and highest of these land forms are pediments carved on a consolidated deposit of andesitic tuff. The younger land forms are the surfaces of a series of alluvial fans and related depositional stream terraces. The nature of these surfaces and associated geologic formations was first studied and reported briefly by the author in connection with the soil surveys of eastern Merced and Stanislaus Counties (Arkley 1954, 1959). In these studies clear-cut relationships were established between land forms, geologic formations and soil series. Subsequently the conclusions drawn with respect to the geology and geomorphic history of the area have been largely substantiated by geologic investigations of Davis and Hall (1959) and Hudson (1960). These geologists used the work of the author extensively in their studies, although some differences in interpretation remain.

Most of the exposed rocks of the area are poorly consolidated Cenozoic sediments, and all except the oldest are nonmarine. The structure of the rocks is simple. The Tertiary rocks are tilted westward throughout the area; the older Quaternary sediments are tilted slightly westward on the west side of a fault zone located about 10 miles east of Turlock. A summary of the formations and related soils found in the area is given in table 1. The distribution of the rocks exposed at the surface is shown in figure 2.

PRE-CENOZOIC

The oldest rocks of the area shown on the map (fig. 2), designated as bedrock complex, are strongly folded meta-andesite and slate. These rocks are described by Clark in the section of this guidebook entitled *Summary of the pre-Tertiary geology of the Western Sierra Nevada metamorphic belt*. Cretaceous rocks are not exposed in the area but underlie the valley, thickening westward from a feather edge about 12 miles west of the bedrock foothills to a thickness of 9,500 feet under the west side of the valley.

FIGURE 1. Schematic section (N-S) 3 miles west of Merced Falls.



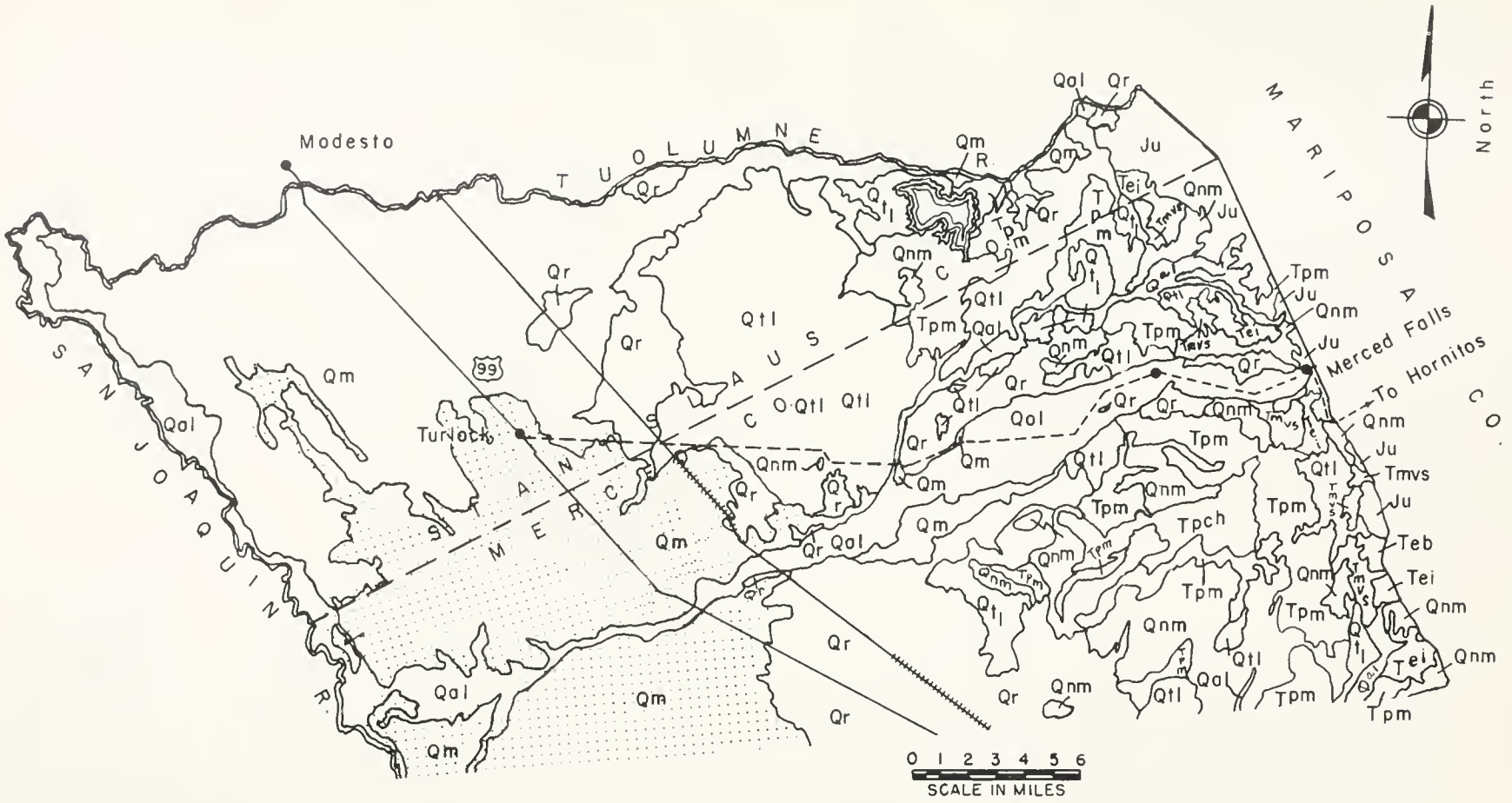


FIGURE 2. Geology of the San Joaquin Valley in the vicinity of Merced River.

Table 1 *.

Formation	Age	Dominant lithology	Maximum thickness	Dominant soil series
Alluvium	Recent	Granitic sand over gravel	50	Grangeville, Tujunga
Sand dunes	Late Pleistocene and Recent	Fine sand	30	Delhi
Modesto	Late Pleistocene	Granitic sand over stratified silt, sand	100	Hanford, Dinuba
Riverbank	Middle Pleistocene	Granitic sand over stratified silt, sand	200	San Joaquin, Snelling
Turlock Lake	Early Pleistocene	Granitic sand over stratified silt, sand	800	Montpellier, Whitney, Rocklin
North Merced (New) (Arroyo Seco?)	Early Pleistocene	Pediment gravel (mainly metamorphic)	30	Redding, Corning
China Hat (New)	Late Pliocene	Pediment gravel (mainly metamorphic)	50	Redding (acid variant)
Mehrten	Early, middle Pliocene	Andesitic tuff and gravel	1,200	Pentz, Peters, Raynor
Valley Springs	Late Miocene	Rhyolitic ash, clay	270	Amador
Ione	Middle Eocene	Sandstone, clay	200	Hornitos
(Several formations)	Late Cretaceous	Marine sandstone, shale	9,500	In wells only; not exposed
	Late Jurassic	Slate	unknown	Daulton, Whiterock
	Late Jurassic	Meta-andesite	unknown	Auburn

* Modified from Davis and Hall (1959) and Hudson (1960).

CENOZOIC

Ione Formation. Resting unconformably on the bedrock complex are the Eocene sandstone and kaolinitic clay of the Ione formation described by Allen (1929). The sandstone has attractive hues of pink, yellow, red, and gray and has been quarried for building stone. This material is described as a fluvial and shoreline marine deposit and contains fossils of *Venericardia planicosta* at the Planicosta Buttes just south of the bridge at Merced Falls. The formation dips about 3° to the west and disappears under more recent sediments a mile or two west of the bedrock foothills. The shallow, acid Hornitos sandy loam is the only soil mapped on this formation.

Valley Springs Formation. The Valley Springs formation rests unconformably on the Ione sandstone. It consists of a fluvial sequence of rhyolitic ash, sandy clay and siliceous gravel. The material is acidic in reaction (pH 4.5 to 5.0) and pale yellow to white in color. The formation is generally considered to be of Miocene age, although Axelrod (1944) considers it to be Mio-Pliocene in age. This rock is exposed in an area only about a mile wide parallel with the mountains, just west of the Ione formation. The distribution of the shallow, acid Amador soil coincides exactly with that of the Valley Springs formation.

Mehrten Formation. The Valley Springs is conformably overlain by the Mehrten formation, an easily recognizable sequence of dark sandstone, conglomerate and claystone beds of late Miocene and Pliocene age, according to Stirton and Goeriz (1942). The material is always more than 50 percent andesitic and often as much as 95 percent andesitic. The formation dips westward with a slope of about 100 feet per mile and thickens to a maximum of 1,200 feet under the center of the valley. It contains beds of moderately hard mudstone which stand out on eroded slopes as prominent ledges, giving rise to "haystack mountains" such as China Hat, a conical peak visible southwest of Merced Falls.

Photo 1. Ione formation dipping 5° W.; hard sandstone capping kaolinitic clays. Recent alluvium in the foreground. View is toward the north.

Photo 2. Mima mound or "hog wallow" microrelief and Amodor soil formed on Valley Springs formation south of Merced Falls. View is toward the south.

Photo 3. "Haystack" hills formed by the erosion of alternately hard and soft beds of the Mehrten formation. Pentz soils on the hill sides; Peters clay on the gentle slopes in the foreground. Three miles north of Snelling.

The Mehrten in the area shown in figure 2 contains few or none of the volcanic mudflows found farther north in the Sierra Nevada, but consists almost entirely of fluvial material reworked from the volcanic deposits. As indicated in the section *Geomorphology of Yosemite Valley* in this guidebook, there is no source of Mehrten formation in the Merced River drainage; its southernmost source was in the headwaters of the Tuolumne River. Therefore the Tuolumne River or some distributary of it must have flowed southward in Mehrten time, and forced the Merced River to a southerly course downstream from Merced Falls. The Mehrten formation weathers easily and gives rise to three distinct dark-gray soils high in montmorillonite—the Pentz, Peters, and Raynor series; the last named is about 3 feet deep.

China Hat Pediment and Gravels. The China Hat pediment, named by Hudson (1960) is an old erosion surface truncating the Mehrten formation. The only remnant of this surface is the high, flat-topped ridge south of the Merced River. It is 1 or 2 miles in width and extends 9 miles west of its easternmost preserved point southwest of Merced Falls. The surface slopes westward from a high point 750 feet in altitude at 45 to 68 feet per mile. The pediment is mantled with a 20- to 40-foot layer of gravel, consisting largely of 2- to 6-inch pebbles and cobbles of vein quartz, quartzite and other hard metamorphic rocks eroded from the foothills of the Sierra Nevada. The pebbles, except for the quartz and quartzite, are strongly weathered; some are completely decomposed.

The China Hat pediment is clearly post-Mehrten, therefore younger than mid-Pliocene. Studies of remnants of a similar surface in Stanislaus County indicate that the China Hat pediment pre-dates the Tuolumne Table Mountain lava flow which has been dated as late Pliocene or early Pleistocene by Taliaferro and Solari (1949). Therefore, the China Hat surface is assigned a late Pliocene age. The relatively steep gradient of the China Hat pediment (fig. 3) suggests that it was tilted during the last major uplift in the Sierra Nevada, and this also is in agreement with a late Pliocene age for the pediment. Hudson (1960) attempts to relate this land form to the Broad Valley stage of Matthes (1930), but a direct connection cannot be found through the lower foothills. A correlation with the Mountain Valley stage seems more probable, but more work is needed to establish the relationship.

The surface of the China Hat gravel is red, acid (pH 4.5-5.0), infertile soil with an iron-silica cemented hardpan, an acid variant of the Redding soil series. It has a pronounced micro-relief of "hogwallows" or Mima mounds which are the result of the activity of pocket-gophers (Arkley 1954).

North Merced Pediment and Gravels. On both sides of the Merced River and also south of the remnant of the China Hat pediment are remnants of another broad westward-sloping erosion surface mantled with 10 to 20 feet of gravel similar to the China Hat gravel. This pediment has an altitude of 500 feet at Merced Falls, of 220 feet 18 miles to the west. Its gradient is much less than that of the China Hat pediment and decreases westward from 22 to 15 feet per mile. The pediment truncates the Ione, Valley Springs, and Mehrten formations, and is thought to be of the same age as the Arroyo Seco pedimenr identified by Gale et al. (1939) 40 to 70 miles to the north. Soil surveys indicate that the surface is well represented in the intervening area. Gale considered the Arroyo Seco pediment to have formed after the last important uplift of the Sierra Nevada. The evidence in this area is in agreement with this idea. The soil formed on the North Merced gravel is the Redding series similar to that formed on the China Hat gravel, but is less acid and infertile. This soil is also mapped on the Arroyo Seco gravel to the north.

Turlock Lake Formation. The Turlock Lake formation is a fan deposit of dominantly granitic alluvium covering the westward extension of the North Merced pediment and resting directly on Mehrten formation where the North Merced gravel had been eroded away between North Merced and Turlock Lake time. The uppermost layer of this formation is a coarse sand from 10 to 30 feet thick which has been weathered to form the Montpellier soil, with a thick red, sandy clay loam subsoil. This layer is underlain by a light gray, thinly laminated deposit of silt and very fine sand 10 to 40 or more feet in thickness. Logs of wells drilled in the Turlock Lake formation and a few outcroppings indicate that at least one buried red soil similar to the Montpellier soil formed from coarse sand lies beneath the silty layer. This weathered sand is in turn underlain by silty material. This clear-cut repeated sequence of silty material overlain by decidedly coarse sand (1-4 mm) was not brought out by Davis and Hall (1959) because of an unfortunate choice of type section. The relationship was quite evident during the soil-survey investigations. Shallow, weakly developed Whitney soil of fine sandy loam texture and Rocklin soil with a thin silica-cemented hardpan are found where erosion has exposed the silty material. The strongly weathered buried soil at the top of the lower sequence suggests that the Turlock Lake formation was actually laid down during two periods of deposition separated by a long interval of weathering.

Within the Turlock Lake formation is a wedge of blue, diatomaceous lacustrine clay which was correlated by

Photo 4. Undulating surface of the Turlock Lake formation with Montpellier coarse sandy loam soil. Twelve miles northeast of Turlock.

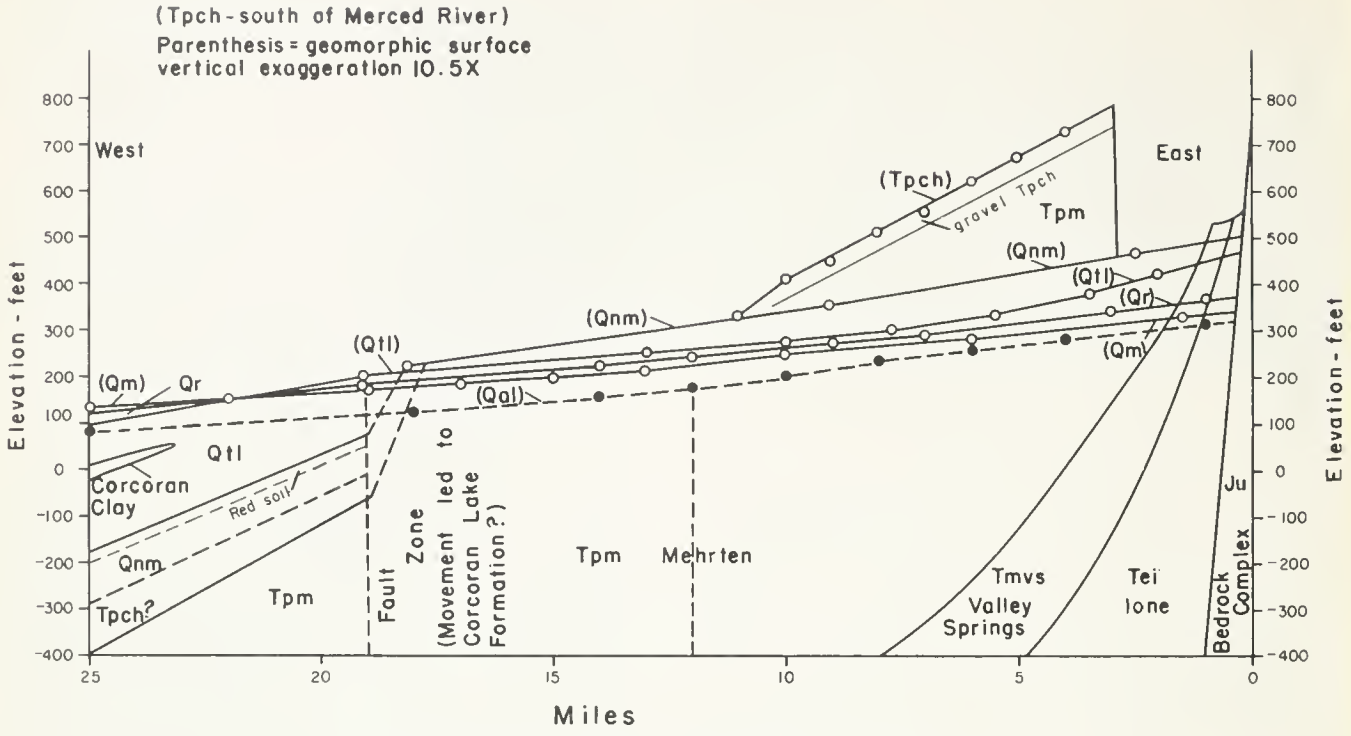


FIGURE 3. Schematic cross-section (E-W) north of Merced River.

Davis and Hall (1959) with the Corcoran clay of Frink and Kuess (1954) (fig. 3). Davis and Hall place this "blue clay" within the Riverbank formation (1959, pl. 4) based upon its position well below a "red clay" layer 100 feet beneath the town of Turlock. This red layer was assumed to be the surface soil of the Riverbank formation. However, the westward extension of the surface of the Turlock Lake formation coincides with this layer, while the Riverbank surface is actually encountered within 10 feet of the surface at Turlock. Therefore the Corcoran clay is a member of the Turlock Lake for tion (fig. 3).

Riverbank Formation. The Riverbank formation c ers the western extension of the Turlock Lake forma and also extends eastward through it to the bedrock fo hills as a depositional river terrace in a valley entrenc through the older formations. This material is cle younger than the Turlock Lake formation, and ha similar but less clear-cut lithologic sequence of fine m rial capped with coarse sand. The dominant soil on

Photo 5. Riverbank surface with Joaquin hardpon soils in the ground; Turlock Lake surface an hil in the background. View is north Eost Avenue, 8 miles east of Tur

ırse sand is a moderately developed brown soil (the elling series) and on the fine-textured and stratified dbeds is a reddish-brown soil (the San Joaquin series) l a brown soil (the Madera series), both with strongly nented silica hardpans.

Modesto Formation. The Modesto formation buries : westward extension of the Riverbank formation and ɔ extends eastward to the foothills through the older mations as a depositional river terrace. The sequence laminated silty material capped by sand evident in : Turlock Lake formation is clearly repeated in the ɔdesto formation. These materials are only slightly athered with either no subsoil development (Hanford l) or a very weakly developed subsoil (Greenfield d Dinuba soils). These soils are only slightly leached d are among the most fertile in the state. In the vicinity Turlock and south into Merced County, the sand has en reworked into dunes by wind action (figure 2).

Alluvium. The Merced River crosses the Pleistocene rmations in a flat-floored valley bordered by bluffs to 60 feet high. The valley is underlain by alluvium ıich consists chiefly of granitic material of fine sandy- ım texture. Where the river has cut down to the ehrten formation, the lower part of the alluvium con- ts of coarse gravel with pebbles and cobbles of granitic d metamorphic rocks. These gravels have been dredged r gold, resulting in the large piles of gravel tailings ɔng the Merced River. The river has been widening floodplain in this area (figure 2). This suggests that new era of pediment cutting has begun in recent time.

GEOMORPHIC HISTORY

On the basis of the soil-survey investigations and the ork of Davis and Hall (1959) and Hudson (1960), the quence of events in the Turlock-Merced Falls area is terpreted to have been as follows:

. Erosion of the Eocene Ione formation into a surface of strong relief was followed by deposition of the Valley Springs and the Mehrten formations which flooded the valley during Mio-Pliocene times with a thickness of 800 feet at Merced Falls, and nearly 1,500 feet in the center of the valley.

2. The China Hat pediment was cut by the Merced River or by local streams flowing across the Mehrten and was mantled with metamorphic gravel derived from the Sierra Nevada.

3. Tilting and uplift of the Sierra Nevada extended westward into the valley increasing the gradient of the China Hat pediment from an estimated original 20 feet per mile to the present 45 to 68 feet per mile. Accelerated stream flow resulted in the erosion of most of the pediment.

4. As the streams approached a more stable gradient, the North Merced (Arroyo Seco?) pediment was formed and mantled with gravel derived from metamorphic rocks.

5. In late Pliocene or early Pleistocene time, renewed erosion resulted in the destruction of a portion of the North Merced pediment and incision of the river to a lower level.

6. At the beginning of the glacial epoch, glacial flour in the form of silt and very fine sand was deposited in the valley, forming the lower portion of the Turlock Lake formation. As glacial activity died out, the coarse sand layer was deposited. This sequence of events was apparently repeated at least once in Turlock Lake time, with an intervening period of weathering of considerable duration.

   Corcoran Lake appears to have existed in the valley during a period of rapid subsidence west of Turlock during the deposition of the Turlock Lake formation.

7. Following a period of erosion and further entrenchment of the river, renewed deposition of glacial outwash gave rise to the Riverbank formation.

8. The Modesto formation was deposited in a similar fashion during the last glacial period.

9. In recent time the river has entrenched the Pleistocene formations to a depth of 20 to 60 feet, and, like the Tuolumne River to the north, has widened its floodplain in the eastern portion of the area where the river bed rests upon the Mehrten bedrock.

10. Subsidence of the valley west of a fault zone 12 to 18 miles west of the foothills continued until late in the Pleistocene and resulted in tilting the Turlock Lake and older formations slightly westward.

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Photo 6. The Yosemite Falls in April. Photo by Mary Hill.

GEOMORPHOLOGY OF THE YOSEMITE VALLEY REGION, CALIFORNIA *

By CLYDE WAHRHAFTIG
U.S. Geological Survey, Menlo Park, California
and University of California, Berkeley, California

INTRODUCTION

Yosemite Valley lies in the Sierra Nevada, a strongly asymmetric mountain range with a broad gentle western slope that rises about 13,000 feet in a distance of 60 miles (200 feet per mile) and an abrupt eastern escarpment that drops 5,000 to 6,500 feet in 5 to 8 miles (about 1,000 feet per mile). The eastern escarpment is the result of displacement in later Tertiary and Quaternary time along a complex system of en echelon and step faults, interspersed with ramps and tilted structures (Lindgren, 1911, p. 39-49; Matthes, 1930, p. 24-25; P. C. Bateman, written communication, 1960; Rinehart and Ross, in press). The western slope, the back slope of the tilted fault block that is the Sierra Nevada, is a broad upland surface of moderate local relief—generally less than 2,500 feet—into which west-flowing streams have incised narrow steep-walled canyons 1,000 to 7,000 feet deep. Yosemite Valley is the headward segment of one of these canyons—that of the Merced River—somewhat widened and greatly deepened by glacial erosion.

The geomorphic history of the Yosemite Valley—and of the western slope of the Sierra Nevada on which it lies—involved: (1) the development of the upland surface; (2) tilting of that surface and carving of deep canyons; and (3) modification of the headward parts of these canyons by glaciers.

UPLAND SURFACE OF THE SIERRA NEVADA

The upland surface of the Sierra Nevada has had a long and complicated history, which is as yet imperfectly understood. Much of the evidence for this history lies in the northern part of the range, where the crystalline bedrock is overlain by a complex of Cretaceous and younger formations, called the Superjacent series by Lindgren and Turner (1894); other evidence lies in the Great Valley of California, where much of the material eroded from the Sierra Nevada was deposited.

Parts of the upland surface may be as old as middle Cretaceous. It is probable that most of the erosion that led to the exposure of the Jurassic and Cretaceous granitic rocks of the Sierra Nevada was accomplished before Late Cretaceous time, for along the western margin of the northern Sierra scattered patches of the fossiliferous marine sandstone of the Upper Cretaceous Chico formation rest on an irregular surface of moderate relief cut on granite and other basement rocks. This sandstone dips southwestward at angles of 2° to 4° (Lindgren, 1911, p. 22-23; Allen, 1929, p. 368; Creely, 1955, p. 96-117). Apparently the shoreline of the Late Cretaceous sea coincided closely with the present edge of the Great Valley sediments, for the Cretaceous rocks north of Oroville appear to correlate with coarse river-channel deposits in the foothills immediately to the east (Creely, 1955, p. 96-117). Wells 10 miles west of the edge of the foothills have encountered, at depths of a few thousand feet below the surface, 2,000 to 5,000 feet of rocks correlated with the Chico formation (Creely, 1955, pl. 3; Piper and others, 1939, p. 87; Davis and Hall, 1959, pl. 3).

The Eocene Ione formation and its correlative rocks, the auriferous gravels, indicate with certainty that by early Tertiary time the granitic rocks of the Sierra Nevada had been exposed to about their present depth, and that the mountain range that resulted from the orogeny that accompanied the intrusion of the granites had been reduced to a surface of moderate to low relief. The Ione formation consists of interbedded quartz sand, kaolin clay, kaolinitic sandstone, and thin beds of lignite, that dip 2° to 5° westward along the base of the Sierra Nevada, and that rest on deeply weathered metamorphic and igneous rocks, or on a deep-red to chalk-white tropical soil developed on these rocks (Allen, 1929). The formation is predominantly continental, but at Merced Falls and elsewhere it contains intercalated sandy beds with marine fossils, indicating that the shoreline of the sea was then close to the present base of the Sierra Nevada (Allen, 1929). At the time the Ione accumulated California had a humid tropical climate, in which laterites and kaolin were formed; at other times in the Cretaceous and Tertiary the climate of California appears to have been cooler, for montmorillonite rather than kaolinite is the common clay mineral of the other sedimentary formations, and feldspar is a common constituent of their sandstones.

The auriferous gravels, which grade into the Ione formation along the western margin of the foothills (Allen,

* Publication authorized by the Director of the U.S. Geological Survey.

Photo 1. View of Yosemite Valley from the top of Half Dome, showing the sheer valley walls incised into the gently rolling upland surface of the Sierra Nevada. The cliff at the left is Glacier Point, its unjointed lower part composed of Half Dome quartz monzonite, and the upper part, broken by vertical joints, of Sentinel granodiorite. The Glacier Point hotel can be seen at the top of the cliff. Sentinel Dome is the white dome rising from the forest directly above the hotel. El Capitan is the cliff on the north wall of the valley opposite the Cathedral Rocks. Washington Column is in the extreme lower right. Photo by U.S. National Park Service.

1929, p. 395-402; Creely, 1955, p. 142-163; Lindgren, 1911, p. 33-37, 40, 86-89), were presumably laid down as stream gravels in a series of well-defined channels or valleys that coursed down the western slope of the Sierra Nevada (fig. 1). Remnants of these deposits now lie on broad spurs between the present west-flowing streams, having been preserved beneath cappings of lava or volcanic mudflows. Because much placer gold was obtained from these gravels during the last century by hydraulic and drift mining, we know a great deal about their extent (Lindgren, 1911). The streams by which they were deposited no longer exist—the drainage pattern of that period was completely buried by later outpourings of volcanic debris—but we know that in general these streams flowed westward from sources near the present crest of the Sierra Nevada, or even farther east. The minimum local relief of the Sierra Nevada at that time in the present foothill region, as estimated from the present height of hills of bedrock above nearby segments of the Tertiary river channels, was about 1,500 to 2,500 feet (Turner and Ransome, 1897 and 1898; Turner, 1894; Lindgren, 1911, p. 37-39, 197-199, 218-219). According to Lindgren (1911, p. 37-39) the Tertiary topography consisted of three elements: a discontinuous line of abrupt ridges 1,000 to 2,500 feet high, extending northwestward near the present foothills and held up by resistant metavolcanic rocks (Logtown Ridge, Gopher Ridge and Bear Mountain, Penon Blanco, and Mount Bullion, fig. 1); northeast of these ridges, a broad northwest-trending valley cut in the soft slates of the Mother Lode belt; and still farther northeast, a rolling plateau cut chiefly on granitic rocks, in which broad Eocene valleys were incised 800 to 2,000 feet.

The Merced River is not bordered by Eocene river gravels, so we do not know what its profile was in early Tertiary time; the blanket of volcanic debris, which preserved the auriferous gravels north of the Tuolumne River apparently did not extend as far south as the basin of the Merced. Matthes (1930, p. 31-50), however, was able to reconstruct the early landscape along the upper Merced River by a study of the present topography. He noted that the upper reaches of lateral tributaries of the Merced River flow with gentle gradient in broad shallow valleys to an abrupt nickpoint, from which their lower courses cascade to the Merced River, which is incised in a narrow canyon several hundred to 3,000 feet below the level of those valleys (fig. 2). By projecting the profiles of the tributaries downstream to the points where they joined the Merced, he was able to reconstruct the profile that the upper part of the river followed at this early stage in the Yosemite region; and Hudson (1960, p. 1554-1557) has now extended this profile down to the Great Valley (fig. 3). The reconstructed profile defines a broad valley incised 800 to 1,500 feet below adjacent mountains such as Half Dome, and having about the same depth as the Eocene valleys farther north. It therefore seems reasonable to assume that most of the cutting of the broad

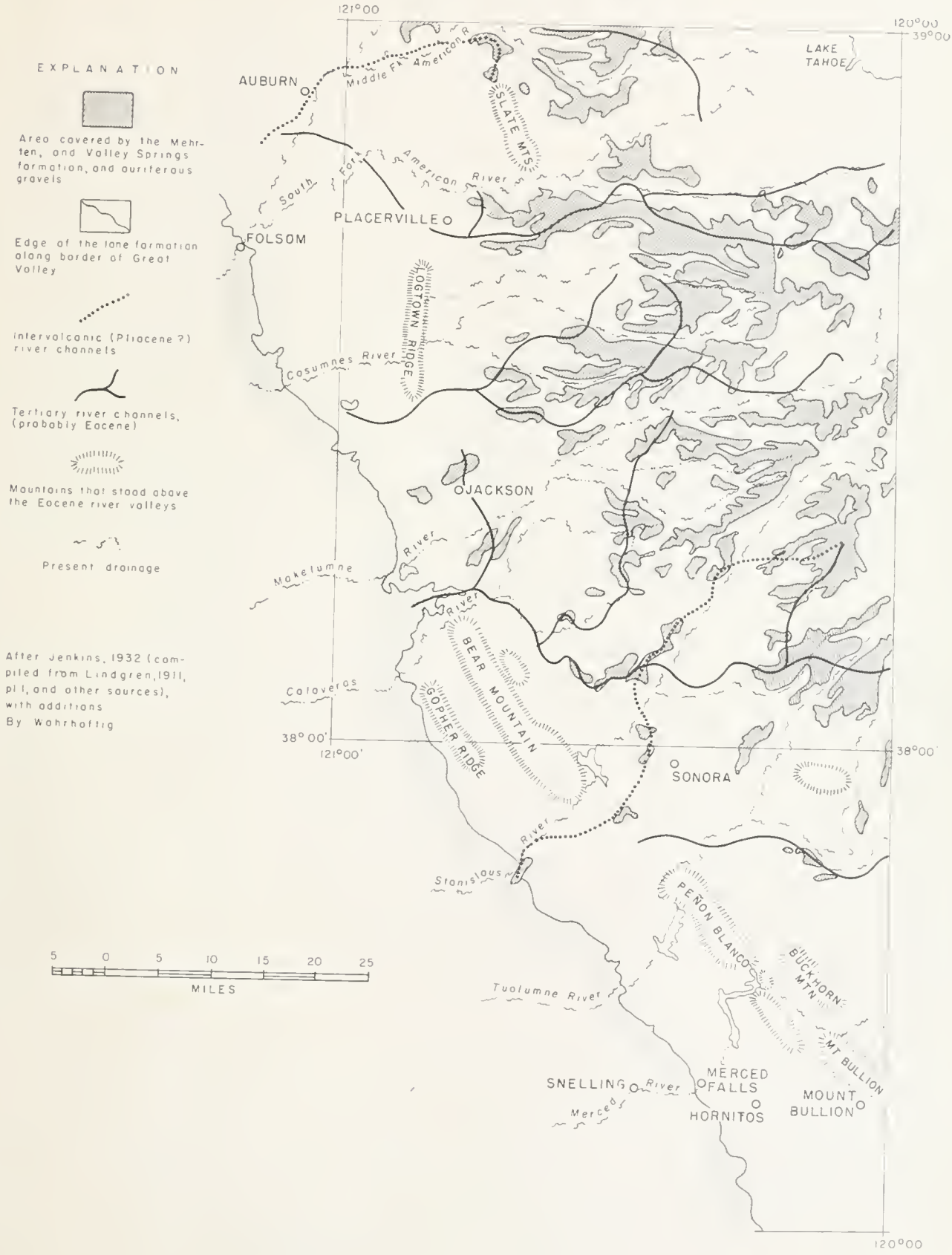


FIGURE 1. Tertiary river channels of the Sierra Nevada.

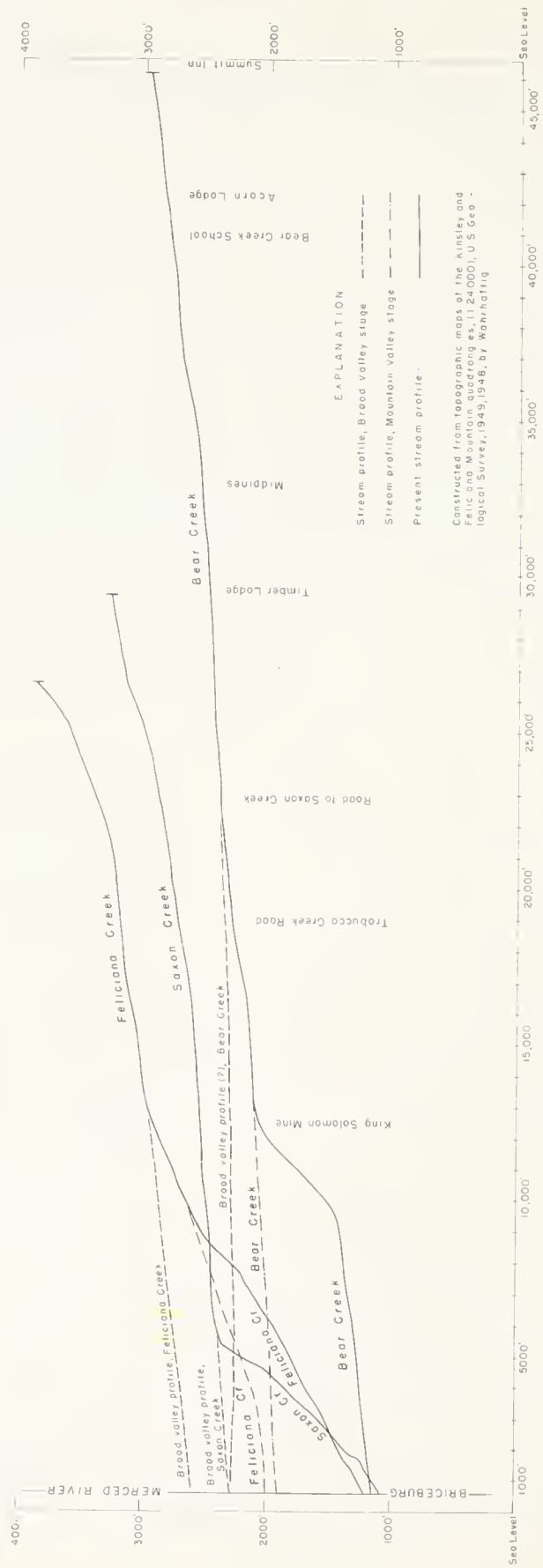


FIGURE 2. Profiles of three tributaries of the Merced River in El Portal quadrangle, California, showing nickpoints to the stages of downcutting of the Merced River.

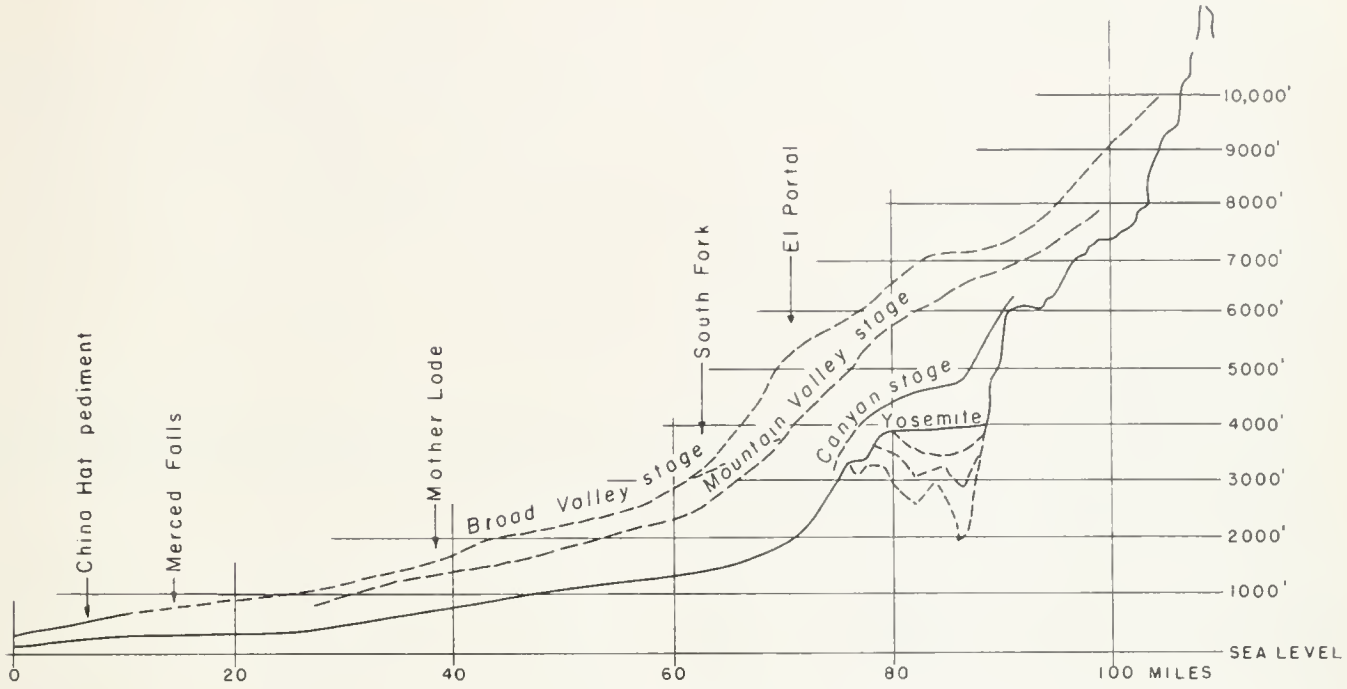


FIGURE 3. Longitudinol profiles of the Merced River (after Hudson, 1960, p. 1551).

valley took place during or before the deposition of the auriferous gravels in the northern Sierra Nevada.*

The Ione formation and the auriferous gravels are overlain by extensive bodies of white rhyolite tuff and associated gravel, which constitute what is called the Valley Springs formation (Allen, 1929, p. 410-419; Piper and others, 1939, p. 71-80). These are dated as probable late Miocene (Davis and Hall, 1959, p. 9). The eruptions that produced the rhyolitic debris initiated the volcanic outpourings that buried the Eocene surface of the northern Sierra Nevada. The relief of this surface may have been reduced by erosion of its more upstanding portions in Eocene, Oligocene, and Miocene time, but the surface itself could not have been uplifted and dissected at that period, for Eocene gravels of the rivers that drained that surface are preserved beneath the Miocene and Pliocene volcanic cover.

The most extensive volcanic outpourings in the northern Sierra Nevada occurred in late Miocene or early Pliocene time (Piper and others, 1939, p. 61-71; Lindgren, 1911, p. 31-33). These constitute the Mehrten formation of Miocene and Pliocene age, a deposit of andesitic volcanic mudflows interbedded with conglomerate and sandstone that consist mainly of andesitic debris. The Mehrten formation has been correlated with the Neroly formation of the San Pablo group in the northern Diablo Range (Davis and Hall, 1959, p. 9). The sources of the volcanics in the Mehrten are breccia dikes along the present crest of the Sierra, from which they were largely extruded in the form of breccia (Curtis, 1954). The eruptions buried the northern part of the range under a volcanic blanket that was about 1,500 feet thick at the west foot of the mountains and 4,000 or 5,000 feet thick along the crest of the range, and that completely obliterated the old drainage of the Sierra Nevada. A new westward-flowing drainage was then developed upon the constructional surface of the volcanic rocks (fig. 1). The southernmost of the mudflows of the Mehrten formation followed the course of the Tuolumne River (Lindgren, 1911, p. 30-32, 218-219). None reached the Merced drainage, so the Merced today is probably in about the same place that it was in early Tertiary time.*

EROSION OF THE MERCED CANYON

Matthes (1930, p. 31-50), in his restoration of the ancient profiles of the Merced River, recognized two stages in the cutting of the Merced canyon, which followed the Broad Valley stage. His determination of the profiles of these stages was based on the same technique that he used for the Broad Valley stage, but here he used intermediate segments of the tributary streams, with nickpoints at their upper and lower ends (see figs. 2 and 4 for examples of the profiles). During the earlier of

* Hudson, on the other hand (1960, p. 1555), places the Broad Valley stage of downcutting in the late Pliocene. Piper and others (1939, p. 78) correlate it with the Valley Springs formation of late Miocene (?) age.

* For the distribution of the Mehrten formation beneath the Great Valley, and its probable influence on the lower course of the Merced River, see the paper by R. J. Arkley in this guidebook.

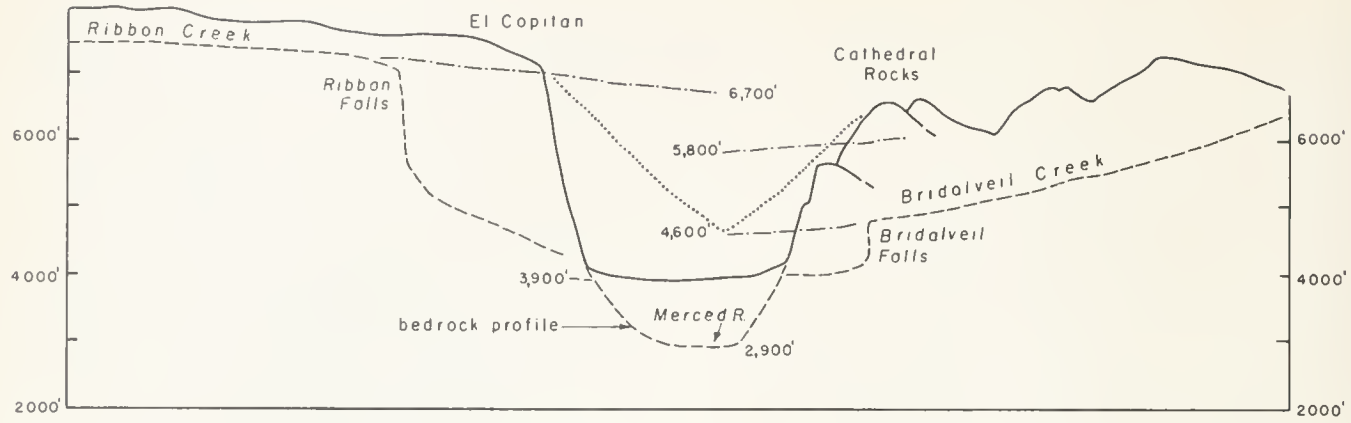


FIGURE 4. Projection, on a north-south plane, of the cross-profile of Yosemite Valley between El Capitan and Cathedral Rocks (solid line) and of the profiles of Ribbon and Bridalveil Creeks (dashed lines). Elevations of Merced River of the Broad Valley stage (6700'), Mountain Valley stage (5800'), and Canyon stage (4600') of downcutting, and profiles on which they are based (dot-dashed lines) are from Matthes (1930, fig. 12, p. 42). Preglacial cross-profile of the valley (dotted line) from Matthes (1930, fig. 27, p. 87). Data for bedrock surface from Gutenberg, Buwalda, and Sharp (1956, fig. 8, p. 1072). Horizontal and vertical scales are the same.

these stages, which he called the Mountain Valley stage, the river flowed in a fairly rugged narrow valley, 1,600 to 2,200 feet below the surrounding uplands and about 600 feet below the level of the Broad Valley stage. The later stage, which he called the Canyon stage, determined the present level of the Merced River in the unglaciated canyon below El Portal and also determined the original preglacial profile in the glaciated part of the canyon above El Portal. The cutting of the China Hat and Arroyo Seco pediments, described by R. J. Arkley in this guidebook, may have occurred during the Mountain Valley and Canyon stages.

Photo 2. View down the lower Merced Canyon from the top of El Capitan. The canyon is incised in valleys of the Broad-Valley and Mountain-Valley stages of canyon cutting; these stages are indicated by the gentle slopes descending to broad flats from the surrounding level ridge tops. Photo by F. C. Calkins, U.S. Geological Survey.

UPLIFT AND TILTING OF THE SIERRA NEVADA

The Merced River and other west-flowing streams of the Sierra Nevada cut their deep canyons because the range as a whole was uplifted and tilted to the west. Estimates made by several men of the amount, nature, and time of this deformation differ widely, partly, no doubt, because they have been based on different kinds of evidence.

The direct estimates involve determination of the amount of deformation of the bedrock profiles of the early Tertiary rivers. The present deformed profiles, determined either from the slope and altitude of channel segments beneath the gold-bearing gravels or by reconstruction from existing topography, have been determined with fair accuracy. The original profiles, from which deformation to the present is measured, must in large part be reconstructed from our knowledge of the factors that control the gradients of debris-carrying streams. Recent investigations on this general problem (Leopold and Maddock, 1953, p. 48-51; Leopold and Wolman, 1957; Hack, 1957, p. 53-74) indicate that the auriferous gravels will have to be studied further before these original profiles can be reconstructed with a precision that is up to modern standards.

Indirect estimates of the deformation include (1) inferences drawn from fossil floras regarding former climates, (2) measurements of displacement on the faults along the east side of the range, and (3) measurement, through subsurface investigations, of the tilting of sedimentary rocks in the eastern half of the Great Valley. The bearing of the second and third lines of evidence is open to question, for neither the faulting on the east side of the range nor the tilting of the sediments in the Great Valley was necessarily quite contemporaneous with the uplift and tilting of the mountains between them, or of the required magnitude; their aggregate effect may have been either greater or less than that.

This section, therefore, will merely describe the views of several writers regarding the amount and time of this deformation without attempting to choose between them.

Lindgren (1911, p. 46) concluded that the Sierra Nevada had been tilted essentially as a rigid block, although he recognized several faults with as much as 500 feet of displacement cutting the auriferous gravels on its western slope. He determined (1900, p. 10) that the tilting at the latitude of Donner Pass amounted to between 60 and 70 feet per mile, which corresponds to an uplift at the crest, now 7,500 to 8,000 feet above sea level, of about 4,500 or 5,000 feet. In his opinion this uplift took place during the eruption of the volcanics which constitute the Mehrten formation, that is, in Miocene and Pliocene time.

Lindgren based his calculations largely on the bedrock profile of the Tertiary Yuba River, which apparently flowed southwestward from the crest of the range for about 35 miles, then turned to flow northwestward, parallel to the presumed axis of tilting, for about 45 miles, and turned again to flow southwestward for about 30 miles to a mouth near the present site of Wheatland, at the east side of the Sacramento Valley. The gradients of the reconstructed southwesterly reaches are 80 to 100 feet per mile, and those of the northwesterly reaches 20 to 30 feet per mile (Lindgren, 1911, pl. 10). Lindgren assumed that the northwest reach had not been tilted and therefore had the average gradient of the stream before tilting; he estimated the tilting, by subtraction, to be between 60 and 70 feet per mile.

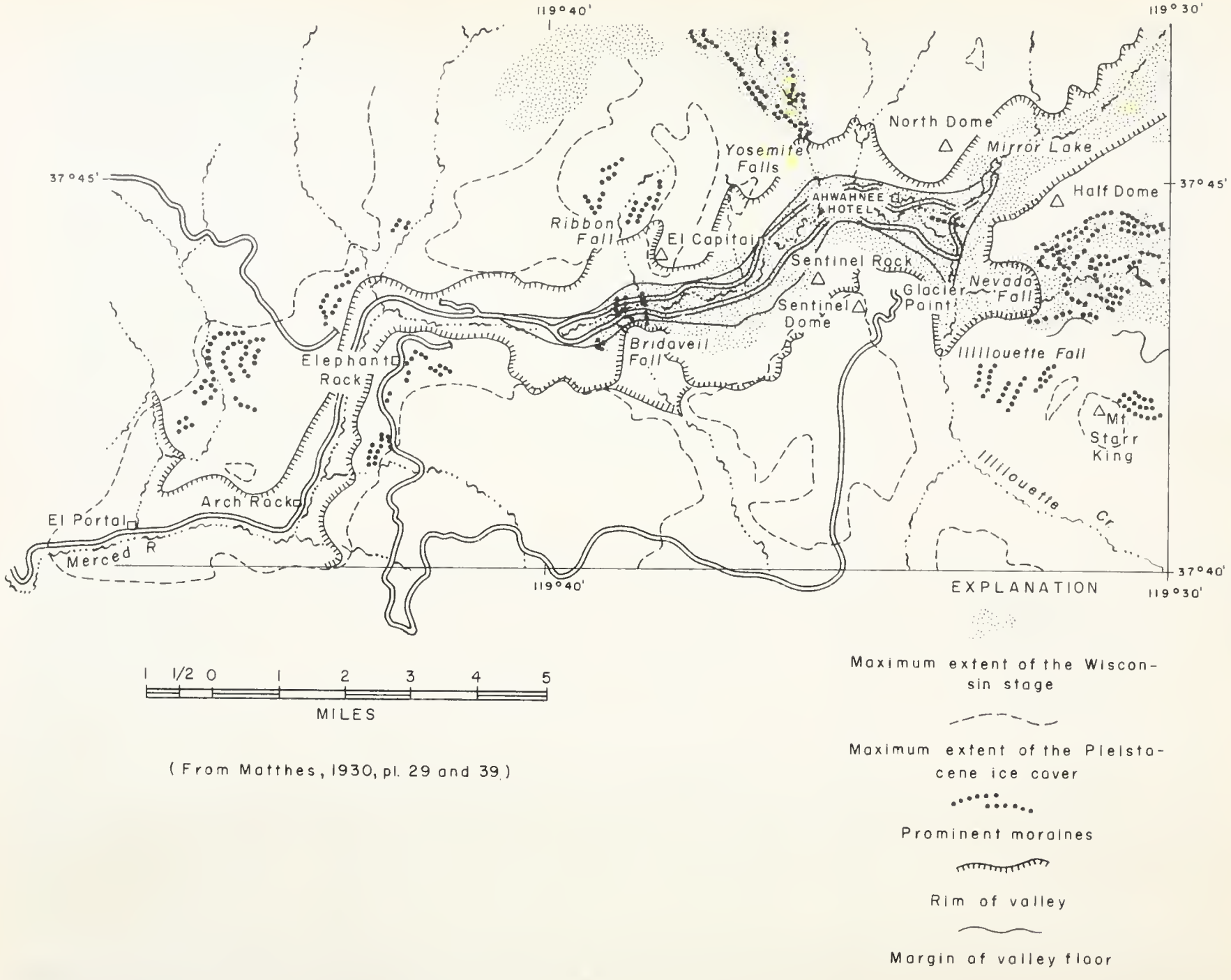
Matthes (1930, p. 44), using a similar method on the reconstructed profiles of the Merced River, but with more assumptions since there were no long northwest-flowing reaches of that stream, concluded that total tilting since the Broad Valley stage, which he placed at the end of the Miocene, had amounted to 72 feet per mile, and that the total uplift of the crest of the Sierra Nevada in Yosemite National Park had been 9,000 feet. He estimated that 6,000 feet of the uplift, and tilting of 60 feet per mile, had occurred since the end of the Mountain Valley stage, which he placed at the end of the Pliocene. The floor of Yosemite Valley was, he inferred, 800 feet above sea level during the Broad Valley stage and 1,800 feet above sea level in the Mountain Valley stage.

Hudson (1955, 1960) has calculated the amount of tilting in the Sierra Nevada through use of the present gradients of differently directed adjacent reaches of the Tertiary streams, taken in groups of three. He assumes that the average gradient in all three adjacent reaches was originally the same, and computes the amount and direction of tilting necessary to produce the present gradients by solving three equations for three unknowns: the original gradient, the amount of tilting, and the direction of tilting. From these computations he has concluded that the Sierra Nevada was deformed not as a rigid block but in a very complex fashion, and, furthermore, that the total uplift at the crest has amounted to less than 2,000 feet in the Lake Tahoe-Donner Pass region and less than 4,000 feet in the Yosemite National Park region. From correlation of the Broad Valley stage of the Merced River with the China Hat pediment (Arkley, this guidebook) Hudson (1960, p. 1559-1560) places the uplift and deformation entirely within post-middle-Pliocene time.

Axelrod (1957) has shown that floras of Miocene and Pliocene age from the Valley Springs formation, the Mehrten formation, and their equivalents in west-central Nevada indicate similar climates, and that they do not indicate the existence of a rain shadow, such as the one now present on the east side of the Sierra Nevada. From his estimates of the range in altitude of the floras, he concludes that the mountains near Lake Tahoe could not have been higher than 2,000 or 2,500 feet in Miocene and Pliocene time, and therefore that the crest of the range has been uplifted 5,000 to 6,500 feet since then. There seems at present to be no way of reconciling Axelrod's views with those of Hudson.

Hoots, Bear, and Kleinpell (1954, pl. 6) show that in the Chowchilla-Merced area of the Great Valley, just south of the Merced River, the base of the Pliocene sediments slopes about 100 feet per mile west-southwestward. In their cross sections, the base of the Pliocene and the base of the Eocene are essentially parallel. If the evidence in the Great Valley can be projected eastward to the Sierra Nevada, one may infer from it that there was no tilting of the range from middle Eocene to Pliocene time, and tilting on the order of 100 feet per mile since Pliocene time. As stated above, however, it has not yet been proved that tilting in the Sierra Nevada was contemporaneous with that in the Great Valley or equal to it in amount.

Somewhat similar evidence is found between Mono Lake and Bishop on the east side of the Sierra Nevada. According to Blackwelder (1931, p. 904) and C. D. Rinehart and D. C. Ross (oral communication), there has been about 3,000 feet of displacement on faults on the east side of the Sierra Nevada since the McGee stage of glaciation. Vertical displacements at least as great as this in the region immediately east of the fault have resulted in deformation of the Bishop tuff of Gilbert (1938), a glowing-avalanche deposit that rests on glacial till at least as old as the Sherwin stage; and that has been dated by the potassium-argon method as about one million years old (Evernden and others, 1957). This tuff, whose upper surface must originally have been nearly horizontal, now ranges in altitude from about 8,000 feet just south of Mono Lake to 3,300 feet in the alluvial sediments south of Bishop (Gilbert, 1938; Bateman, 1956, pl. 1, 2 and oral communication, 1957; Rinehart and Ross, 1957, and oral communication, 1960). The deformation just east of the Sierra Nevada may have taken place long after the tilting and uplift of the range was completed; it may represent the collapse of the Owens Valley-Mono Lake block, which may have involved either greater or less displacement than the uplift of the range.



(From Matthes, 1930, pl. 29 and 39)

FIGURE 5. Sketch map of Yosemite Valley, showing extent of glacial ice.

While the dates arrived at by these indirect means thus differ considerably, the writers quoted all place the major uplift and tilting of the range in late Pliocene and early Pleistocene time. In regard to the total amount of uplift, their estimates tend to agree more nearly with those of Lindgren and Matthes than with those of Hudson.

GLACIAL EROSION OF THE YOSEMITE VALLEY

In the summer-dry Mediterranean climate of California, the present snowfall on even the highest areas in the Yosemite National Park is barely sufficient to maintain a few small cirque glaciers on the shaded north sides of 12,000- to 13,000-foot peaks. During the maximum extent of Pleistocene glaciation, however, snow accumulated on ridges no more than 9,500 feet high, and, except on slopes that were too steep, the surfaces above that altitude were blanketed with snow and ice. The glaciers fed by these snowfields descended about 25 miles down the Merced Canyon to El Portal and beyond, reaching altitudes as low as 2,000 or even 1,700 feet; they also went down the Tuolumne Canyon to like altitudes and for a distance of about 40 miles. At its maximum extent the Merced Glacier completely filled Yosemite Valley and spilled slightly over the rim onto the uplands on either side (Matthes, 1930, p. 50-102) (fig. 5).

Glaciers advanced down the Merced Canyon at least three and perhaps four times. During the later stages of glaciation, ice only partially filled the Yosemite Valley, and glaciers of the latest major stage, the Tioga, did not even reach the valley but stopped just short of Nevada Falls (Blackwelder, 1931, p. 907). Little remains of the oldest moraines except scattered boulders of quartzite, schist, and other highly resistant rocks; any boulders of intrusive rocks that can still be identified are mostly decomposed to grüss (granite sand), and the bedrock surfaces on the uplands that were glaciated have weathered down several inches or several feet, leaving glacial erratics perched on pedestals of disintegrated bedrock. The deposits of the youngest glaciation, on the other hand, are quite fresh, and large areas of bedrock that were covered by the latest glacier are so little weathered that the glacial polish on them still glistens in the sunlight. The stages of glaciation of the Yosemite region that have been recognized by various authors are shown in table 1.

The glaciers profoundly changed the shape of the original Merced Canyon. They ground off projecting spurs, planed back parts of the walls to vertical cliffs, gouged a deep basin in the valley floor, and gave the valley the characteristic U-shaped cross-profile. According to Matthes (1930, p. 89-98) the glaciers eroded mainly by quarrying and plucking, joint blocks being lifted into the glacier by freezing of water in the cracks between them. Grinding and polishing appear to have played a relatively minor part in the erosion of the valley. Matthes has shown that the greatest deepening and widening of the valley occurred where the rocks were most closely jointed, and that many of the massive, almost unjointed monoliths were eroded slowly or not at all. As was pointed out in the paper in this guidebook by Calkins and Peck, the various intrusive rocks in which the canyon was cut differ widely in the extent to which they are jointed, and the more mafic rocks are in general more closely jointed than the more siliceous rocks. Joints are indeed scarcest in the Half Dome quartz monzonite, which is less siliceous than the granites in El Capitan, but this may be because it forms an exceptionally large intrusive body. Some depressions were eroded, however, along fissures that cut indifferently across all kinds of rocks, even across Half Dome quartz monzonite. Where

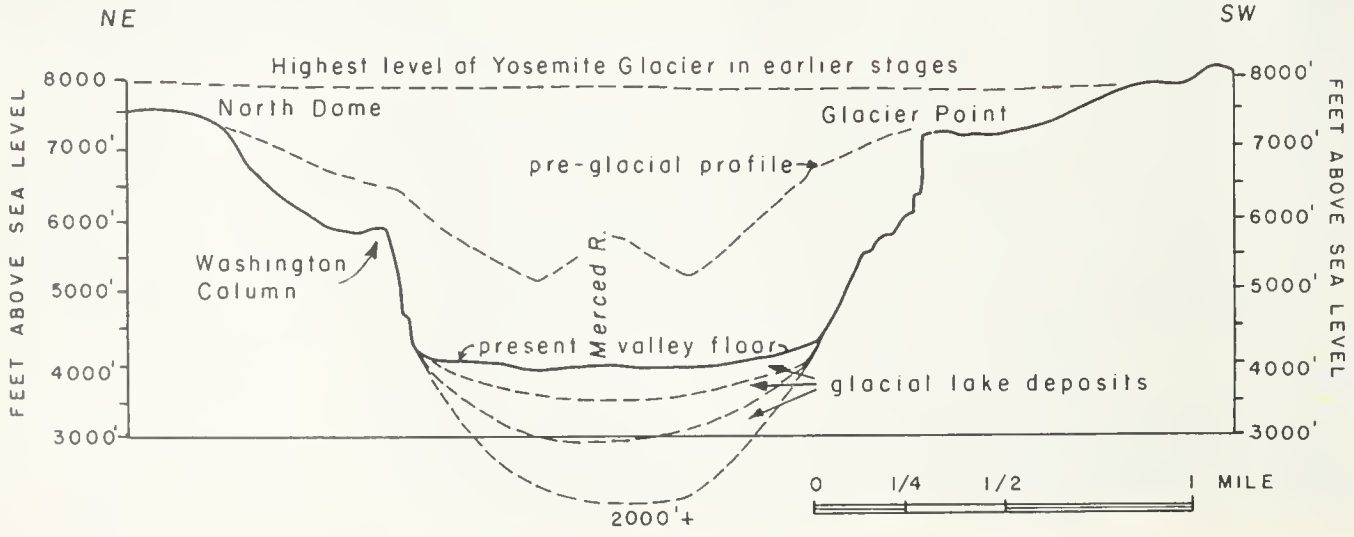
Photo 3. Glacial polish, glacial striae, and erratics on Moraine Dome, Little Yosemite Valley. Photo by Ralph H. Anderson, U.S. National Park Service.

Table 1. Correlation and characters of glacial stages in Yosemite Valley.

Glacial stages			Position of ice terminus on Merced River	Weathering (after Birman, 1957, p. 55)	
Matthes (1930)	Blackwelder (1931, p. 907-908)	Birman (1957, p. 220-222)		Till	Bedrock
"Little ice age" (Matthes, 1942, p. 214) (2,000 B.C. to present		Matthes Recess Peak Hilgard(?)	Cirques on Mt. Lyell (includes modern glaciers).	Unweathered (unstable on most recent moraines).	(Glacial polish completely preserved.)
	Tioga	Tioga	Head of Nevada Falls.	Moraines fresh, undissected.	Not much weathering of bedrock; much polish preserved.
Wisconsin	Tahoe	Graveyard	Foot of Bridalveil Falls.	Moraines moderately weathered; dissected by gullies 10 to 40 ft. deep.	Little or no erosion of bedrock; polish preserved only on aplite pegmatite, and fine volcanics.
El Portal	Sherwin?	Tahoe	Few miles west of El Portal.	Moraines weathered to 10 ft.; dissected by gullies 10 to 70 ft. deep.	Boulders perched 1 in.; pegmatite dikes protrude 3 in. Much weathering on surface; weathering pits rare or shallow.
Glacier Point		Sherwin		Bedrock weathered to 6 in. below surface and weathering pits 6 in. deep.	Most boulders weathered; no morainal forms preserved.
	McGee	McGee	(Not recognized on west slope of Sierra.)	Rock pedestals and mafic inclusions more than 6 in. high.	

the Merced Canyon was cut into rocks in which the joints are widely spaced, as it is in the gorge between El Portal and the mouth of Cascade Creek, its cross profile is still essentially V-shaped, although morainal deposits on the walls of the gorge show that it was occupied by the earlier ice. The relatively even longitudinal profile of the preglacial Merced River was converted by glacial plucking into a series of giant steps separating glacially scoured basins, the nearly vertical steps occurring where massive unjointed rock crosses the canyon.

FIGURE 6. Cross-profile of Yosemite Valley between North Dome and Glacier Point (after Matthes, 1930, p. 86, with corrections from Gutenberg and others, 1956, fig. 8).



The proportionate amounts of erosion accomplished in the preglacial canyon stage and during glaciation are indicated by the cross-profiles, (figs. 4 and 6), in which Matthes' reconstructions of the canyon stage of the Merced River are superimposed on the present bedrock profile of the Yosemite Valley. The glacier cut even deeper, however, in the valley itself, than Matthes imagined, for seismic exploration reported by Gutenberg, Buwalda, and Sharp (1956) has shown that the bedrock surface beneath the valley floor is generally more than 1,000 feet below the surface of the alluvium and is fully 2,000 feet below it just south of the Ahwahnee Hotel. According to these authors (p. 1074) the remarkably great deepening at this place was due to the great thickness and velocity of the ice at the junction of the Tenaya and Merced glaciers, and to the fact that glacial quarrying was made possible by sheet spalling in otherwise massive rock, due to net decrease of load through erosion, even under several thousand feet of ice.

The glaciers deposited extensive systems of morainal ridges and discontinuous patches of till and erratics on the uplands bordering the valley (Matthes, 1930, pl. 29). It has generally been possible to trace the outer limits of the various glacial stages by following the morainal deposits along the rim. There are only three places where moraines can now be seen on the valley floor or in the canyon of the Merced below it. This is partly because some other moraines were washed away by swiftly flowing glacial meltwater in the narrow Merced gorge, but partly, perhaps, because some of them are buried under lake sediments on the valley floor. The moraines that we can see, however, are important for the interpretation of the history of the Yosemite Valley.

A set of six moraines between Bridalveil Meadow and El Capitan Bridge protrudes above the lake sediments and may have been in part responsible for holding in the lake. These are taken by Matthes to mark the maximum advance of the Wisconsin ice in the Valley (the Tahoe glaciation of Blackwelder's terminology). A similar set of moraines encloses the lower end of Little Yosemite Valley, about half a mile above Nevada Falls. According to Blackwelder (1931, p. 907-908), these are much fresher than the moraines at Bridalveil Meadow and mark the maximum extent on the Merced River of the ice of his Tioga stage. A third set of moraines, as yet unexplained, may be seen at the head of the Yosemite Valley near the junction of Teneya Creek and the Merced River.

During the glacial advances, the Merced River, overloaded with great quantities of coarse debris delivered to it by the Merced Glacier, built an extensive valley train on the floor of its canyon, aggrading its bed several score of feet. Remnants of this valley train can be recognized as patches of outwash gravel preserved against the walls of its canyon downstream from El Portal. The outwash gravel stands out from the prevailing dark-hued metamorphic rocks of the canyon walls because of the light tone of the granitic boulders of which it is composed. Outwash gravel of at least two ages can be recognized: in the older gravel the large granodiorite boulders and nearly all the small granitic pebbles have decomposed to sand; in the younger gravel, which in some places overlies the older, the pebbles and boulders are still relatively fresh. The fine sand and silt in the glacial debris were carried out to the floor of the Great Valley, where they constitute the Turlock Lake, Riverbank, and Modesto formations of Davis and Hall (1959) described by R. J. Arkley in this guidebook.

Gutenberg, Buwalda, and Sharp (1956, p. 1064-1069) recognized three layers in the fill beneath Yosemite Valley. The lowest layer, about 1,000 feet thick, has a seismic velocity of 3 kilometers per second, and they regard it as a lake deposit of the Glacier Point stage or older (p. 1077). The intermediate layer, which is about 600 feet thick and has a seismic velocity of 2½ kilometers per second, they regard as a glacial-lake deposit of the El Portal stage. The upper layer, which is about 300 feet thick and has a seismic velocity of 1¾ kilometers per second, extends downvalley only as far as Bridalveil Fall. They regard this as a glacial-lake deposit of Matthes' Wisconsin stage.

POSTGLACIAL AND INTERGLACIAL SCULPTURING OF THE CLIFFS

Postglacial and interglacial sculpturing of the cliffs has taken place by two different but somewhat allied processes: by prying out of roughly equant blocks bounded by joints (which are more numerous in some rocks than in others) and by spalling of huge curved sheets in joint-free rocks, thought to have resulted from expansion due to release of the weight of overlying rocks (Matthes, 1930, p. 114-117; Jahns, 1943). The most thoroughly jointed rocks of the valley are the diorite near its western end, and cliffs of this rock have disintegrated to form the massive talus aprons called the Rockslides, across from Wawona Tunnel. The least jointed rock is the quartz monzonite exposed in Half Dome and other domes overlooking the head of the valley, which are almost literally monolithic and whose tops were shaped by spalling. Sentinel Dome is the only one near the valley that consists of a different rock, namely the El Capitan granite. The domes achieved their rounded forms long before the advent of glaciation; they are not *roches moutonees,* for they were never overridden by ice.

The diorite of the Rockslides and the quartz monzonite are at opposite extremes in character of jointing. The valley walls between them consist of rocks that are intermediate in this respect, as has been pointed out in the paper by Calkins and Peck in this guidebook. The taluses, three of which are of great size, were probably formed mostly in postglacial time, by the breaking down of diorite and other closely jointed rocks that are now for the most part covered with talus. Those east of the Cathedral Rocks and east of El Capitan contain some glacial debris.

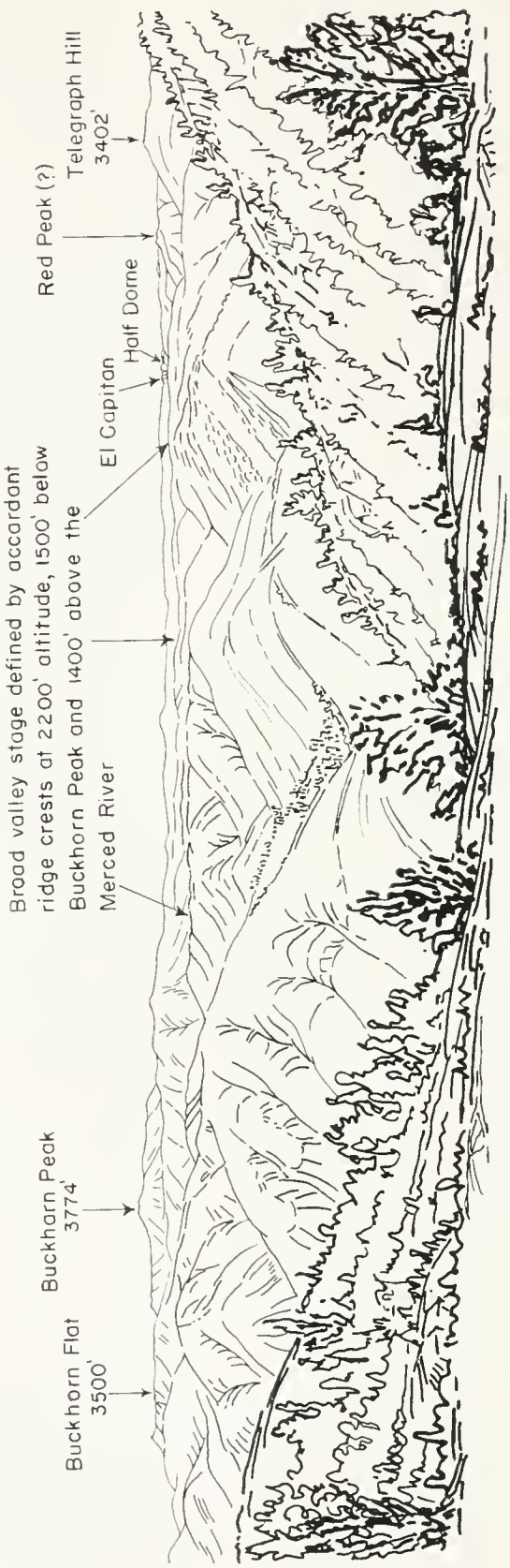


FIGURE 7. Panorama east and north from Pine Tree mine, showing the upland surface of the Sierra Nevada, and the Broad Valley stage and modern canyon of the Merced River. (Sketched from photographs.)

Photo 4. Northeast side of Half Dome, shawing exfoliation on a gigantic scole. The arrow paints to two men half way up the slope. In the fareground is an old shell disintegrating ta granitic sand. Photo by F. C. Calkins, U.S. Gealagical Survey.

A sheeting that is flat rather than curved, induced apparently by wetting and drying or freezing and thawing, and controlled in part by joints, has led to the steepening of many of the cliffs of sparsely jointed rocks over which the waterfalls plunge, converting what may once have been foaming cascades to the free-plunging falls we see today. Most of the falls, particularly at their lower ends, are in recesses that could not have been carved by ice moving down the Merced River (note particularly Ribbon Fall and the base of Bridalveil Fall). The walls of these recesses are marked by closely spaced fractures which indicate that slabs of granite, parallel to the rock surface, have broken away from beneath the waterfalls. These fractures are particularly common near the lower ends of the falls. Talus cones, also, are piled beneath some of these falls, the debris of the fallen slabs. An example of this process, steepening a cascade to form a vertical waterfall, can be seen on the west side of Sentinel Rock.

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Part II—ROAD LOGS

FROM HAYWARD THROUGH YOSEMITE VALLEY VIA TRACY, PATTERSON, TURLOCK, AND MERCED FALLS

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PLATES

Plate 1. Geologic map and section of the southern part of the western Sierra Nevada metamorphic belt ..... In pocket

Plate 2. Guide map to Highway 50, Hayward to Tracy, California In pocket

Frontispiece, Part II, opposite. Winter, Yosemite Valley, California, by Ansel Adoms.

ROAD LOG 1

U.S. HIGHWAY 50 FROM HAYWARD TO TRACY, CALIFORNIA *

By HOLLY C. WAGNER
U.S. Geological Survey, Menlo Park, California

and FREDERIC R. KELLEY
California Division of Mines and Geology
San Francisco, California

Plate 2, *Guide map to Highway 50, Hayward to Tracy, California,* accompanies this road log.

Between San Francisco and Hayward the field trip route follows U. S. Highway 50 across the Bay Bridge and turns onto the Nimitz Freeway (State Route 17), by-passing Oakland. As the Bay Bridge is crossed toward Yerba Buena Island, Alcatraz Island may be seen about 3 miles to the left, past the San Francisco waterfront. The buildings of the Federal Penitentiary are built on sandstone referred to the Franciscan formation and similar to the sandstone passed through at the entrance to the tunnel on Yerba Buena Island. This sandstone also serves as the anchorage foundation for cables suspending the western part of the Bay Bridge. From the east side of Yerba Buena Island, the Berkeley Hills can be seen on the skyline ahead. Jurassic, Cretaceous, and Tertiary rocks, which have been complexly folded and faulted, underlie the Berkeley Hills. The nearly straight west-facing front of the hills generally coincides with the Hayward fault zone, the locus of several earthquake epicenters in historic time. The route traverses the bay-margin flats to the Tracy turnoff (19.6 mi. from the west abutment of the Bay Bridge) where it leaves the Nimitz Freeway and turns eastward.

Mileage

0.0 Directly beneath the first overhead east of the Nimitz Freeway (Foothill Blvd. overhead—about 2.1 mi. east of the Nimitz Freeway) where the route rejoins U. S. Highway 50. This point is in the Hayward 7½′ quadrangle, about 1½ miles east of the west border (see pl. 2). The Hayward fault zone, whose west limit was crossed about 0.2 mi. back, is about one-fourth mile wide in this area; the east limit of the fault zone crosses U. S. 50 just beyond this set of overheads but is not visible.

0.1 The gray exposure in the roadcut on the left is east of the Hayward fault zone and is largely mafic igneous rock, probably of Jurassic age (Ji on pl. 2). Much of the igneous rock is coarse grained and locally appears to be composed entirely of saussuritized feldspar; altered pyroxenes are common in small areas. The exposed rock is intensely sheared, and serpentine marks many of the shear surfaces. The outcrop may be a multiple intrusion, and the several fine-grained "glassy" pods and zones that crosscut the body may represent selvages along the borders of separate small intrusives. The brownish zone at the top of the exposure reflects the depth of weathering.

* Publication authorized by the Director, U.S. Geological Survey.

Mileage

0.3 Hill with eucalyptus trees to left is capped by Pleistocene Leona rhyolite (Ql on pl. 2). Arenaceous shales of the Upper Jurassic Knoxville formation are here brought in contact with the mafic igneous rocks by the West Chabot fault, which is older than, and does not offset, the capping rhyolite.

0.5 Brownish outcrops to right are shales of the upper part of the Knoxville formation (Jku). The sequence consists of nearly vertical thin beds of weakly metamorphosed shale and sandstone. The beds average about 1 inch in thickness and are locally sheared and brecciated. They are well bedded and have interlaminations of silicified(?) siltstone. Low hill to left is underlain by Lower(?) Cretaceous Oakland conglomerate. The alluvium-covered trace of the East Chabot fault, which separates the Oakland conglomerate from the Chico formation, is crossed about one-half mile to the east (pl. 2).

2.0 Gravels are exposed in lower parts of roadcuts to left and directly under, and just beyond the Castro Valley Boulevard overhead. These gravels have been dated Pleistocene on the basis of vertebrate fossils found to the north.

Mileage

2.3 Leaving Castro Valley. Fairly good exposures of steeply dipping sandstone beds of the Lower(?) and Upper Cretaceous Chico formation (Kc) can be seen in roadcuts for the next few miles.

4.1 Steeply dipping beds of dark-bluish (brownish-weathering) shale of the Chico formation on left.

4.6 Thin-bedded, gray (brownish-weathering), nearly vertical sequence of shale and siltstone in roadcut on left is in fault contact with massive grayish-brown sandstone near east end of cut. This fault is the northern extension of the Stonybrook fault mapped by Hall (1958) in the adjacent Dublin quadrangle. It has been revealed here by new roadcuts made since Robinson (1956) mapped the Hayward quadrangle. Folding in Tertiary rocks shown on plate 2 just beyond this point is not visible from highway.

4.9 Massive, grayish-brown sandstone in contact with thin-bedded, brownish-weathering sequence of sandstone and siltstone in large roadcut on left. Weathering has emphasized shearing and crenulations in the thin-bedded sequence in upper part of exposure. Difference in attitude of beds in west half of cut suggests fault.

6.0 Entering Dublin 7½ minute quadrangle (pl. 2). Terminology in this quadrangle is somewhat different from that in the Hayward quadrangle. Cross section B-B′ on plate 2 depicts structure one-half mile ahead.

6.5 Exposure of middle Miocene Sobrante sandstone (Monterey group) in roadcuts to left. Lower Cretaceous Niles Canyon formation of Hall (1958) underlies hills to right.

7.3 Summit. Middle Miocene Oursan sandstone (Tmo) exposed in roadcuts. Outcrop on skyline about one-fourth mile to left is hard conglomeratic sandstone of the middle member of the upper Miocene Briones sandstone (Tmbm). One-half mile to the east this conglomeratic sandstone caps prominent ridge to left of highway, and at end of ridge the strike swings northwest around the axis of a northwest-plunging syncline.

8.1-8.3 Small outcrops of the lower sandstone member of the Briones (Tmbl) in roadcuts to left and right.

8.4 Dublin fault crosses road. Exposures poor.

8.7 Middle (conglomeratic) member of Briones (Tmbm) visible on hilltop to left. Lower (sandstone) member of Briones (Tmbl) in roadcuts.

9.0 The Livermore Valley may be seen stretching ahead. This valley is apparently a structural depression. On the west the valley has been downdropped along the Calaveras-Suñol fault; it may also have been downdropped along several northwest-trending faults that extend into the valley from the east, under the alluvial cover. Drilling for oil and gas has shown the presence of faults below the surface and a measure of the relative downward movement is supplied by the thickness of 8,000 to 10,000 feet of conglomerate of the Pliocene Orinda formation indicated by Hall (1958, pl. 2).

9.6 Passing under Foothill Road (State Hwy. 21) overhead. Calaveras-Suñol fault crosses road at this point but is concealed by alluvium. Cross section C-C′ is 0.1 mi. ahead (pl. 2).

10.1 Mount Diablo (elev. 3,849′) can be seen on skyline to left. This mountain was a guiding landmark in early Spanish days, and since 1851 has been the point of origin for land surveys of a large part of northern California and Nevada. On its south flank are steeply dipping Cretaceous and Tertiary beds; its core is composed of Jurassic rocks of the Franciscan formation. On the northeast side the Cretaceous and Tertiary sequence contains coal beds and white sands of economic interest in rocks of Eocene age.

10.9 Pastel-painted buildings to left are housing for Camp Parks, U. S. Army.

12.4 Alameda County Rehabilitation Center on left. To the right in the middle distance are stockpiles of processed gravel recovered from the alluvial deposits of Arroyo del Valle and Arroyo Mocho southwest of Livermore. Much of the gravel used in the Bay area comes from large gravel pits in this vicinity.

12.9 Entering the Livermore 7½ minute quadrangle.

13.5 Low hills on left are underlain by nonmarine conglomerate and sandstone of the Pliocene Orinda formation. One and one-half miles ahead Hall's map (1958) shows dips of 80°-85° in these beds; some are overturned.

16.5 Crossing Hall's cross section F-F′ (pl. 2).

19.8 Entering the Altamont 7½ minute quadrangle. Livermore gravels of Clark, 1930 in low hills on both sides of road.

20.5 Livermore road junction. Lawrence Radiation Laboratory, a division of the University of California, about two miles to right. The Livermore facility was established in July 1952 and covers more than 600 acres. The program at the Laboratory (1961) includes investigations concerning physics and engineering of fission and thermonuclear devices; nuclear ram-jet propulsion (Project Pluto); critical assembly and reactor research; controlled release of thermonuclear energy (Project Sherwood); basic nuclear-particle research with various types of accelerators; and industrial applications of nuclear explosives (Project Plowshare).

23.0 Crossing over Western Pacific and Southern Pacific railroads. First roadcut on right exposes sandstone and some thin pebbly sandstone beds of the Cierbo formation. The Greenville fault crosses the road just beyond this roadcut (pl. 2) but is not exposed.

23.2 Roadcuts for next 3 miles expose westward-dipping beds of sandstone and shale of the Panoche formation of Late Cretaceous age. The unconformity with the overlying upper Miocene Cierbo is poorly shown.

25.2 Summit of Coast Ranges, here only about 1,040 feet in elevation.

26.2 Good exposure of west-dipping well-bedded shale of the Panoche formation on right.

26.5 Approximate axis of the Altamont anticline. Ahead the beds dip to the east.

27.2 Passing under Western Pacific Railroad overhead. Mileage checkpoint.

27.5 Entering the Midway 7½ minute quadrangle.

28.4 Small fault cuts sandstone and shale beds of the Panoche formation in roadcut to left. Beds to east of fault dip more steeply than those to west.

28.7-29.0 Excellent exposures of sandstone and shale of the Panoche formation.

29.1 On hillslopes to right can be seen discontinuous outcrops of several hard beds of sandstone of the Panoche formation. Hill to left of road in near distance is capped by the hard basal conglomerate of the upper Miocene Neroly formation (Tnss). These beds unconformably overlie the Panoche formation (see cross section A-A′, pl. 2).

Photo 1. Uncanformity between the Panoche formotion of Lote Cretaceous age and the Neroly formation of lote Miocene age; view narth. Sandstone and shale beds of the Ponache are overlain by less steeply dipping conglomerate and sandstone beds of the Neroly.

Mileage

29.5 ***STOP 1.*** Byron Turnoff. Because of freeway traffic we wish to stop the buses off the main road where the exit road turns off. Passengers REMAIN IN BUS; geology is pointed out through bus windows. Buses will then go 1,000 feet ahead to a small side exit, turn around, and return to the freeway.

Unconformity between Neroly formation (upper Miocene) and Panoche formation (Upper Cretaceous). The sandstones and shales of the Panoche formation strike about N. 20° W. and dip about 20° NE. The sandstone beds are generally yellowish gray, 1½ to 4 feet thick, and locally show prominent cross bedding and convolute bedding. The sandstones are medium-to coarse-grained, and are made up predominantly of subangular to rounded, fairly well-sorted quartz grains. Feldspar, biotite, chlorite, and dark grains are present but not abundant. The shale beds of the Panoche are thin (⅛" to 2"), are light gray to yellowish orange, and are slightly silty and carbonaceous. Thin (½") sandstone beds are commonly intercalated. The moderately fissile finely micaceous shale is predominantly clay and is closely jointed, breaking to small rhomboid fragments.

The Panoche is overlain unconformably by conglomerate of the Neroly formation which lies upon the truncated edges of the sandstone and shale at an angle of about 15°. No weathered or humic zone occurs at the top of the Panoche, and the surface is grooved in a N. 25° E. direction. The grooves are filled with conglomerate in which the pebbles range in size from ½" to 3" but average 1" to 1½". All pebbles are well rounded and are mostly volcanic rocks of andesitic composition held in a matrix of medium- to coarse-grained sandstone. Lenticular stringers

Mileage

of sandstone occur in the upper part of this basal conglomerate, which grades upward into the overlying sandstone. The sandstone is medium gray and is essentially a medium- to coarse-grained lithic wacke containing quartz and many dark grains. It is about 30 feet thick and is locally cross bedded. The sandstone unit lenses eastward to about 10 feet in thickness, and an overlying pebble-conglomerate unit nearly merges with the basal pebble-conglomerate bed. The upper conglomerate is locally cemented and breaks across the pebbles. Generally, however, the pebbles weather out in relief from the matrix. Locally the sandstone has a distinct purplish-blue cast.

29.7 Midway fault crosses road and repeats conglomerate at the base of the Neroly formation on east side of valley. Cross section A-A' crosses road at this point (pl. 2).

29.9 Upper (shale) member of the Neroly formation (Tnsh).

31.1 Roadcut on left shows lake clays in sharp contact with sands and gravels (mapped as Tulare formation of Pliocene and Pleistocene (?) age by Reiche, 1950, p. 4). Gravels contain subangular to rounded pebbles of finely veined brownish-red chert, white quartz, reddish-brown volcanic porphyry, and several varieties of greenstone. Crossbedded sands are interbedded with the gravel, but the lake beds, above, are nearly horizontal.

31.5 Delta-Mendota Canal, a major water transportation facility in the northern part of the San Joaquin Valley. This canal carries water from the delta area of the Sacramento and San Joaquin Rivers southward to supply the west side of the San Joaquin Valley with irrigation water. At the main pump station, which is 4 miles north of here; the water is

Mileage

lifted about 150 feet and flows southward nearly 120 miles to Mendota. The grade of the canal is about 3 inches per mile and near the south end regional subsidence of land has changed the grade and created flowage problems. Subsidence has amounted to about 10 feet since 1937 and in the area of maximum depression along the canal, about 15 miles northwest of Mendota, is about ½-foot per year. The subsidence is apparently a result of withdrawal of deep groundwater.

32.7 San Joaquin Valley ahead. Coast Range-Diablo Range runs southeastward to the right. Mt. Oso is the highest prominence in the hills to the right and forms part of the Franciscan core of the Diablo Range. Several manganese deposits occur in the vicinity of Mt. Oso in the Ladd-Buckeye area. The principal producer has been the Ladd mine, which began operations in 1867. Intermittent production to 1950 totalled an estimated 30,000 to 50,000 tons of manganese ore. The manganese occurs as gray rhodochrosite and bementite in massive white chert lenses in rocks of the Franciscan formation. Eight miles beyond Mt. Oso is the Red Mountain magnesite district, which yielded approximately 870,000 tons of magnesite between 1905 and 1945. The magnesite occurs as replacements of serpentine in shear zones in a large ultramafic intrusive body.

34.0 Town of Tracy ahead. At the northeast edge of town is the Tracy Gas Field. This field was the first commercial gas field found in northern California and the first California field to produce gas commercially from Cretaceous strata. The discovery well was completed in August 1935 and produced from the Tracy gas sand in the Panoche formation at a depth of about 4,000 feet. Maximum annual production from the field was more than 3 trillion cubic feet in 1936. The field is currently (1961) "shut-in".

34.4 Leaving strip-map area (east boundary of Midway 7½ minute quadrangle).

38.8 Tracy High School.

Mileage

41.6 Leave Highway U.S. 50. Turn right on State Highway 33 toward Vernalis and Patterson. The McMullin Ranch field, a new discovery, lies about 6 miles due east of this point. The discovery well was completed May 4, 1960 at 5,925-5,945 feet in sands of Late Cretaceous age. As of this writing (February 1961) active development is in progress. The Vernalis gas field lies east of Highway 33 about 7 miles ahead. This field was discovered in January 1941, and first commercial gas deliveries began in May 1942. The gas is produced from as many as 10 zones between 3,000 and 5,000 feet depth. For further information see Manlove's article on the Vernalis gas field in Bulletin 181. A fourth producing area nearby, called the Vernalis-Southwest field, lies about 5 miles southwest of the Vernalis field. The discovery well was completed in August 1959 with production from Upper Cretaceous sands at 4,560 feet. Payne (1962, pl. 17), shows correlations of the subsurface units in the Tracy and Vernalis gas fields with well sections farther to the south.

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ROAD LOG 2

TRACY TO EL PORTAL VIA PATTERSON AND TURLOCK, CALIFORNIA *

By CLYDE WAHRHAFTIG

U.S. Geological Survey, Menlo Park, California, and
University of California, Berkeley, California

and L. D. CLARK
U.S. Geological Survey, Menlo Park, California

Plate 1, Geologic map and section of the southern part of the western Sierra Nevada metamorphic belt, accompanies this paper.

Mileage

0.0 Junction of Highways U.S. 50-California 33. Turn right (south) on Highway 33.

9.1 Junction California 33 and 132.

17.9 Junction California 33 and road to Grayson and Modesto.

24.5 Turn left (east) onto Patterson-Turlock Road.

27.4 Cross San Joaquin River.

40.2 Center of Turlock (intersection Main and U.S. 99)—turn right (south) to first street past stoplight.

40.3 Turn left (east) off U.S. 99 on East Ave.—road to Snelling.

40.2 to 46.0 The road crosses the depositional surface on top of the Pleistocene Modesto formation of Davis and Hall (1959), equivalent to the upper part of the late Pleistocene Victor formation (Piper and others, 1939). The Victor formation is an alluvial fan. For a geologic description of the area between Turlock and Merced Falls, see the paper by R. J. Arkley in this guidebook.

46.0 The road leaves the smooth depositional surface and enters slightly rolling topography carved in the Quaternary Riverbank formation of Davis and Hall (1959), equivalent to the lower part of the Victor formation. Outcrops of reddish sandy alluvium along the road at mile 47.8 are probably of this formation.

48.2 To the north can be seen a line of low, flat-topped hills carved in the Turlock Lake formation of Davis and Hall (1959).

52.2 The low, flat-topped hill about a quarter of a mile to the southwest (right) consists of Mehrten formation, of Miocene and Pliocene age, capped by a thin layer of Arroyo Seco gravel of middle or late Pleistocene age (R. J Arkley, this guidebook).

52.5 The road enters the area mapped as Turlock Lake formation by Davis and Hall, characterized by rolling country carved in reddish sandy alluvium.

* Prepared cooperatively with the U.S. Geological Survey.

Mileage

54.9 North bank of Dry Creek. The roadcuts along the grade down to the creek expose two layers of thinly bedded fine sand and silt interbedded with coarse sand. These may represent glacial lake deposits (glacial rock flour) laid down by the Merced River. The terrace traversed by the road beyond Dry Creek is underlain by the Riverbank formation of Davis and Hall (1959).

55.4 The China Hat pediment (see article by R. J. Arkley, this guidebook) can be seen across the Merced River, above the trees at 2:00 o'clock.

Just beyond this point the road descends 20 feet to the terrace surface of the Modesto formation.

57.2 On the skyline to the east across the river can be seen the westward-sloping China Hat pediment.

57.9 The road descends the terrace to the modern floodplain of the Merced River. The small outcrop at the base of the bluff is of thinly bedded fine sand and silt. This is overlain by 20 to 30 feet of well-sorted medium-grained sand of granitic detritus.

61.6 The abandoned grade visible at intervals on the right is that of the Yosemite Valley Railroad, which extended from Merced to El Portal and operated from 1907 to 1945. Its chief business was freight, but the railroad carried many Yosemite-bound travelers during the summer.

65.5 Snelling. Small white courthouse at Snelling, erected in 1857, was the first in Merced County.

Between Snelling and Merced Falls the road passes piles of dredge tailings. The gold mining dredges are large barges with chains of scoop buckets that gnaw away on one side of the artificial pond on which the dredge floats. The buckets feed into a large trommel on the dredge that separates the coarse gravel from the fine gold-bearing sand. This sand passes from the trommel over a complicated series of riffles which trap the gold. The barren gravel is carried up a long stacking arm by an endless belt and dumped on the side of the pond opposite from where it was dug. By excavating at one end and back-filling at the opposite end, the dredge carries along the pond on which it

Mileage

floats as it mines the gold. The dredge is anchored to the shore by cables and swings from side to side by pulling alternately on the cables, digging and stacking as it goes. This back and forth swinging from a fixed point gives the curious cross ridges of the dredge tailings; from the air these tailings piles look like stacks of coins that have fallen over.

The gravel that has been dredged here is apparently post-glacial alluvium deposited in the shallow steep-walled valley that the Merced River carved in the Pleistocene Modesto and Riverbank formations. The large size of the boulders in this gravel is very puzzling, for the Pleistocene alluvium contains no boulders of this size so far out from the mountains. In addition to gold, a small amount of platinum was recovered from the dredgings.

With luck, one can see to the south the profile of the China Hat pediment.

72.0 Merced Falls.

72.1 Merced Falls dam and powerplant on right. The dam rests on the westernmost outcrop of bedrock, which consists of black slate with interbedded graywacke.

72.3 Sawmill ruins on right.

72.5 Cross abandoned grade of the Yosemite Valley Railroad. Exposures of steeply dipping Upper Jurassic slate. The metasedimentary rocks extending from here eastward to Stop 1 are on the western limb of a large anticline (pl. 1). Although the beds are in places complexly folded, tops are westward in intervening areas where bedding is not crumpled.

72.7 Continue straight ahead on Exchequer Dam road.

72.8 Cleavage and bedding in slate at left dip steeply.

73.0 Cleavage still dips deeply, but in minor folds bedding crosses the prominent cleavage.

74.7 **STOP 1.** Lunch. Stream-polished exposures on the north bank of the Merced River show details of the structure of much-deformed slate and graywackes. Some graded graywacke beds can be found. The most prominent structures here are minor folds that plunge southwest and southeast at angles of 70° and 80°. These small folds are superimposed on beds that already dipped steeply as a result of earlier folding about nearly horizontal axes. The Jurassic slate of this area differs from most of that exposed farther north in the abundance of minor folds and in the steep plunge of fold axes.

Return to Snelling-Hornitos Road.

75.7 Cross Merced River.

76.7 **STOP 2.** The flat-topped hill just west of the road is capped by about 100 feet of coarse cross-bedded sandstone and conglomerate of the Ione formation, which rests on deeply weathered Jurassic slate. At the base of the hill can be seen outcrops of black unweathered slate. Near the top of the hill, the sandstone can be seen resting on bleached white slate. The sandstone contains pebbles of bleached slate, volcanic rocks, and quartz. It is largely a quartz-kaolin sandstone with a very low percentage of heavy minerals, all extremely resistant to weathering, and was apparently derived from the erosion of a terrain that had been deeply weathered in a tropical climate. Casts of *Venericardia planicosta* have been reported from the sandstone in this hill (Allen, 1929, p. 361).

The flat-topped hills to the southeast, which slope gently southwestward, are also capped by about 100 feet of similar sandstone of the Ione, resting unconformably on the upturned edges of the Jurassic slate. If the hill crests are projected by eye eastward, they will be seen to coincide roughly in height with the even-topped ridges in the distance to the east, the foothill ridges of the Sierra. These ridges are underlain by metavolcanic rocks.

Mileage

76.9 to 79.9 The road here passes through rolling country surmounted by the flat-topped mesas of the sandstone of the Ione. On the low, rolling hills can be seen the curious "hogwallow" microrelief of evenly spaced mounds 2 to 3 feet high, and about 20 to 40 feet across. See article by R. J. Arkley in this guidebook, for a discussion of the origin of this microrelief.

79.9 Whitish-weathered schistose felsite, probably Upper Jurassic.

82.5 Road crosses into Jurassic metavolcanic rocks.

82.7 Roadcuts in schistose metavolcanic rocks.

83.3 Hornitos (take left fork).

83.4 Adobe and stone buildings, some in ruins but others still occupied. Hornitos was settled in 1850 by Mexicans who were invited to leave the town of Quartzburg, about 4 miles to the northeast. Joaquin Murietta, a bandit idolized by some in Mother Lode history, is alleged to have once escaped through a tunnel leading from a building here. One of the ruined buildings once housed the store of D. Ghirardelli, who later went into the chocolate business. From the Wells Fargo office, established in 1852, gold shipments of $40,000 per day are reported, and the population of Hornitos reached a high point of about 15,000. The name "Hornitos" means "little ovens" and was derived from the dome-like bake ovens constructed here by a group of Germans.

84.6 Schistose amphibolite in roadcuts.

85.4 Old placer diggings in Burns Creek on the right.

87.1 Quartzburg school. Site of the gold-rush town of Quartzburg.

88.7 Take left fork of road.

90.7 Hunter Valley Road on left. Continue straight ahead toward Bear Valley.

91.1 Hunter Valley extends to the northwest (left). Bedded Upper Jurassic tuff dips about 60° northeastward in roadcuts on the right.

92.7 View ahead of Bear Valley and Bullion Mountain. The floor of Bear Valley, at an elevation of about 2,000 feet, is probably a surface of the Broad Valley stage of the Merced River. Bullion Mountain, which has a present elevation of 4,200 feet, threfore probably stood at least 2,200 feet above the Broad Valley stage of the Merced River (approximately equivalent in age to the Ione formation or the auriferous gravels). Bullion Mountain is held up by resistant metavolcanic rocks while Bear Valley is carved in soft slate of the Mariposa formation. The Mariposa formation is separated from the metavolcanic rocks by the Melones fault zone which is concealed by mass wastage debris on the lower slopes of the mountain.

93.8 West contact of the Mariposa formation.

94.4 Junction State Highway 49 at Bear Valley. Turn left (north) on Highway 49. The town was the site of Col. John C. Fremont's headquarters after he had purchased the Mariposa land grant in 1847. Fremont operated lode gold mines and a stamp mill until 1863.

The road north is over the rolling upland surface of Bear Valley at altitudes of 2,000 to 2,300 feet. From Bear Valley to the Pine Tree mine (Stop 3), and back to Mariposa, the route follows the Mother Lode, a geographic belt 2 to 3 miles wide in which a system of discontinuous eastward-dipping quartz veins crops out. Lode gold deposits are not restricted to the Mother Lode belt, but within it

Mileage

the quartz veins and ore bodies are more numerous and can be followed farther in mining than elsewhere in the Sierra Nevada. The gold is associated with the quartz veins, but in many mines gold in the quartz is relatively scarce; the ore was formed by replacement of the rock adjacent to the veins. Many Mother Lode veins and ore bodies are within the Melones fault zone, but they are related to smaller faults that are apparently younger than the chief movements of the fault zone.

95.8 Edge of the canyon of the Merced River. The topography drops abruptly away to Hell Hollow, the ravine directly below, and the Merced River, 1,400 feet below and 2 miles north of this point.

96.9 Contact between Mariposa formation and serpentine. The Mariposa formation is sheared for a distance of about 100 feet westward from the serpentine as a result of movement on the Melones fault zone. The fault zone here includes the serpentine and the sheared part of the Mariposa formaton.

97.2 **STOP 3.** Pine Tree mine. Walk out to point north of iron tanks while bus is turning around. North and east from this point can be seen the Merced Canyon and also the Broad Valley surface, which is marked by accordant ridge crests at or just above our level on the north side of the river. These accordant crests rise north of us to the base of a mountain (Buckhorn Peak), which is crowned by a flat area more than a mile across (Buckhorn Flat, altitude about 3,400 to 3,500 feet) that is nearly 1,200 feet above the Broad Valley stage of the Merced River. Buckhorn Flat is cut across steeply dipping metavolcanic rocks. Northeast of Buckhorn Flat, and several hundred feet below it, is an extensive gently rolling upland cut across the steeply dipping Paleozoic Calaveras formation. Patches of auriferous gravels have been found on this upland (Turner and Ransome, 1897).

Due east can be seen the High Sierra, with a few of the higher peaks (possibly Mt. Clark and Red Peak, 11,500-11,600 ft.) rising from behind the even-topped forest-covered ridges of the Sierra upland that form the skyline. At the head of the Merced Canyon, the tops of El Capitan, Half Dome, and Clouds Rest, three of the famous monuments of Yosemite Valley, can be seen rising slightly above the forested plateaus. If, in mind's eye, the canyons be filled in up to the level of the Broad Valley stage, a rough picture of the appearance of the Sierra Nevada in Eocene time can be obtained.

The Pine Tree gold mine, at the head of the ravine to the south, recovered ore from the Pine Tree vein, discovered in 1849, and from the Josephine vein, discovered shortly thereafter. The mine operated intermittently from 1849 to 1944, part of the time under the ownership of Col. Fremont, and has a recorded production of about $3,400,000 from 8 miles of workings. The total production is probably greater than $4,000,000. Mariposite, a bright-green chrome mica, is among the minerals found here. (Notes on mine statistics and history in this road log are from Bowen and Gray, 1957.)

Return to Bear Valley on California 49.

100.0 Town of Bear Valley. Ruins of adobe and stone buildings on left.

105.1 Site of Mt. Ophir Mint. This was an officially sanctioned private mint established in 1851; for a short time it manufactured hexagonal $50 gold slugs to ease a currency shortage. The white quartz vein and diggings at the top of the hill ahead mark the site of the Mt. Ophir mine. Discovered in 1849 or 1850, the mine was operated intermittently until 1914. Recorded production is $85,703, but total production is estimated at about $270,000.

Mileage

106.7 Town of Mt. Bullion. The Princeton group of mines is on the Mt. Bullion-Cathay road at the southern outskirts of Mt. Bullion. The Princeton mine, discovered in 1852, produced about $5,000,000 in gold from workings that extended to a depth of 1,250 feet. Most of the ore carried between $4 and $7 per ton in gold, but near-surface ore yielded about $70 per ton. No sustained mining has been carried on since 1927.

108.2 Contact between serpentine in the Melones fault zone and greatly sheared slate and conglomerate of the Mariposa formation. The long axes of the elongate conglomerate pebbles are nearly vertical.

108.8 Road follows contact between serpentine on the right and metavolcanic rocks on the left for the next half mile.

111.5 Junction California 49 and California 140. Turn right (southeast) into Mariposa. "Mariposa" means butterfly.

112.2 Rest stop. Turn around. Leave Mariposa traveling toward Yosemite Valley on California Highway 140.

112.9 Junction California 140 and 49. Continue ahead on 140. From here to mile 117.2 steeply dipping metavolcanic rocks with some interbedded slate are exposed in the roadcuts.

114.4 Small body of talc-antigorite schist enclosed in metavolcanic rocks.

116.5 Mariposa summit. 116.5 to 121.0: the highway passes down the valley of Bear Creek, a broad gentle valley probably graded approximately to the Merced River of the Broad Valley stage (Hudson, 1960, fig. 2. p. 1551).

117.2 Highway enters an area underlain by a granitic rock.

117.8 Highway passes from the granitic area back to metavolcanic rocks.

121.0 The grade of Bear Creek steepens somewhat, the canyon narrows, and the stream has carved incised meanders. The segment of the stream from 121.0 to 123.1 was probably graded to the Merced River of the Mountain Valley stage.

122.8 Bridge over Bear Creek.

123.1 **STOP 4.** Bear Creek here plunges over a fall held up by the resistant metavolcanic rock and descends the abrupt canyon ahead to the Merced River. This is probably the nickpoint between the segments of Bear Creek graded to the Mountain Valley stage (above) and to the present stream in its canyon (below).

123.7 Contact between steeply dipping metavolcanic and metasedimentary rocks, both parts of the Calaveras formation of Paleozoic age.

123.7 to 125.4 Steeply dipping planar structure in Paleozoic slate exposed on the left is cleavage. Bedding is in general nearly parallel to the cleavage, but often crosses it.

125.4 Briceburg.

125.5 **STOP 5.** Slate and thin-bedded chert (Calaveras formation) are here greatly sheared and the only structures remaining are the steeply plunging lineations and minor folds related to the last stage of deformation. From here to mile 130.5, the Calaveras formation consists of phyllite derived from siltstone that locally contained interbedded chert. Bedding is preserved in part of this interval, but in other parts has been destroyed by shearing as it is here.

Granitic boulders are abundant in glacial outwash resting on water-polished bedrock in cuts on the south side of the road at Stop 5. Since the gravel consists largely of well-rounded boulders of granite and granodiorite, it must have been transported by the river, for the bedrock for many miles upstream from this point consists of metasedimentary rocks. Over the outwash gravel is colluvium derived from the slope above.

Photo 1. Canyon of Bear Creek. At the head of the canyon is a fall which is held up by resistant metavalcanic rock and which separates segments of the creek graded to the Mountain Valley stage (above) and to the present river in its canyon (below).

Photo 2. Glacial outwash overlain by colluvium, near Briceburg. Outwash consists largely of boulders of granite and granodiorite, transported by the river from bedrock exposures many miles upstream.

Mileage

126.6 Boudinages in steeply-dipping mafic dike in large cut on the right.

127.8 **STOP 7** (return trip). Outwash gravel exposed in the roadcut may indicate two layers of outwash, separated by a period of dissection when ice retreated in the headwaters of the river. In the lower 10 feet of the gravel many of the boulders of granodiorite and granite are rotted to granite sand; maximum size of the boulders is about 4 feet, but this is no larger than boulders now being moved by the Merced River on the other side of the road. The upper 20 feet of the exposure, separated from the lower part by a row of boulders slumped from the hillside above, consists of finer gravel (about 1 foot average size) composed of largely unweathered boulders of granite and granodiorite. The upper gravel may be of Tioga or Graveyard (of Birman, 1957) age, probably the latter, and the lower gravel Tahoe or Sherwin in age (see table 1, Wahrhaftig).

129.6 Crossing Feliciana Creek, one of Matthes' classic areas of the Broad Valley stage.

129.7 Quartz ladder veins in dikes to the right.

130.5 Thin-bedded metachert of the Calaveras formation, locally contorted. The light-gray-weathering more massive rock is limestone, traceable from here to about 1 mile north of the quarry at mile 132.0.

131.6 Small granitic stock to the north across the river.

131.8 Inactive limestone quarry. Limestone from this quarry was used in Merced for the manufacture of Portland cement. The geologic structure on hillsides to the north (left) is brought out by the resistant metachert and limestone beds.

133.6 **STOP 6.** Geologic marker. Tightly and complexly folded metachert and black phyllite of the Calaveras formation.

Mileage

The folds all plunge steeply, but the bearing of the fold axes and attitudes of axial planes are not consistent.

134.2 Landslide debris in roadcut on the right. The scarp at the top of the slide, not visible from this point, is near the crest of the ridge. Looking downstream from this point the V-shaped canyon of the Merced River is well displayed.

134.5 Young glacial outwash gravel or hydraulic mine tailings on right.

135.0 Bridge across the South Fork of the Merced River.

136.5 Waste dumps of the Clearing House mine can be seen to the east across the river. The ore was discovered in 1860, and before mining ceased in 1937, the mine had yielded more than $3,350,000 in gold, some silver, and small amounts of copper and lead. Granodiorite exposed on hill north of the mine.

Photo 3. V-shaped canyon of the Merced River 0 mile below the mouth of the South Fork. On the top of the ridge on the skyline are preserved remnants of a gently rolling surface produced during an earlier cycle of erosion.

136.9 Southwestern contact of an isolated granitic pluton.

137.1 Gold Star mine on right. The mine produced small amounts of gold from 1936 to 1952.

137.3 On the spur on the canyon wall to the north (left) can be seen the trace of the incline where log-laden flatcars were lowered from spur lines on the gently rolling upland surface above to the main line of the Yosemite Valley Railroad near river level.

137.4 Dumps at the Rutherford gold mine are visible north of the river. The production is not recorded but there are several reports of high-grade ore.

137.8 Outwash gravel in roadcut.

138.2 Northeastern contact of granitic pluton.

138.3 Spheroidally weathered boulders of granitic rock.

Mileage

139.7 Southwestern contact of a granitic body. The highway crosses metamorphic rock from 139.7 to 140.2.

140.2 Northeastern contact of a granitic body.

140.4 The flat area to the left marks an abandoned meander of the river.

140.6 The sheet-iron structure at the base of the hill on the far side of the river is a mill that processed tungsten ore from mines in this vicinity.

141.1 At this point, the canyon of the Merced River widens out and is U-shaped. Downstream from this point the canyon is V-shaped and winding, and there is some question as to how far below this point ice actually extended. There is no question that ice reached this far downstream on the Merced River in the oldest glacial stages recognized on the west side of the Sierra.

141.2 Tunnels in the sharp ridge north of the river are workings of the El Portal barite mine. Most of the nearly 400,000 tons of barite produced was used in oil-well drilling mud. The mine has been idle since 1948.

142.0 Bridge across Merced River.

142.3 Metamorphic rocks across river to the right.

Mileage

142.6 El Portal. (Gasoline station at east end of town.)

142.7 Contact between Calaveras formation and part of the Sierra Nevada batholith.

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ROAD LOG 3

EL PORTAL TO WAWONA TUNNEL AND A CIRCUIT OF YOSEMITE VALLEY, CALIFORNIA *

By DALLAS L. PECK
U.S. Geological Survey, Menlo Park, California

CLYDE WAHRHAFTIG
University of California, Berkeley, California, and
U.S. Geological Survey, Menlo Park, California

and FRANK C. CALKINS
U.S. Geological Survey, Menlo Park, California

EL PORTAL TO THE EAST PORTAL OF THE WAWONA TUNNEL

Mileage

0 El Portal (Standard Oil Company Service Station). The contact between the Calaveras formation (late Paleozic) and the granitic rocks of the Yosemite area trends due north a few hundred feet east of here. The marginal intrusive rocks include coarse diorite and some norite. Farther east is the V-shaped gorge of the Merced River, which, although glaciated during two pre-Wisconsin stages when the glaciers extended about one mile below here, was not glaciated during the Wisconsin. El Portal was formerly the terminus of the Yosemite Valley Railroad. For reference see the sketch map of the Yosemite Valley area (fig. 2), the generalized geologic map (Calkins and Peck herein, fig. 1), and the glacial map (Warhaftig, herein, fig. 5).

3.5 Arch Rock Entrance Station, National Park Service.

3.6 Arch Rock. Two large fallen blocks are in contact at the top but are separated at the bottom by enough space for passage of the old road. Talus of Arch Rock granite †, is exposed in a quarry on the north side of the road. The granite contains sparse inclusions of an unidentified darker-gray rock similar in appearance to the granodiorite at the Gateway.

4.7 Elephant Rock is straight ahead.

6.0 Junction with the Coulterville Road, the first road into Yosemite Valley (completed as a toll road on June 17, 1874).

6.2 Wildcat Creek. El Capitan granite is exposed at the falls just west of here.

6.5 Cascade Creek. El Capitan granite (probably Cretaceous) is exposed in a nearby cliff, and some large fallen blocks of it can be seen from the road.

Mileage

8.4 Junction with the Big Oak Flat Road. The original road, which lies farther up the slope, was completed one month after the Coulterville Road. At the road junction are exposures and talus of the older diorite (described as "diorite of the Rockslides" by Calkins and Peck). Here the diorite contains light-colored aggregates consisting mainly of plagioclase that probably formed as the result of metamorphism by the nearby El Capitan granite.

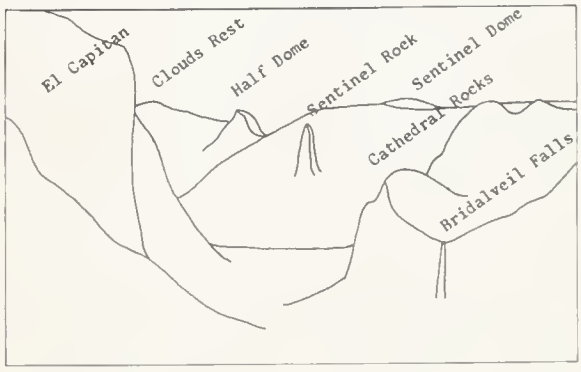
9.4 Turn right across Pohono Bridge.

10.4 Turn right on Wawona Road.

12.2 Stop in parking lot at the east portal of Wawona Tunnel. View to the east of El Capitan, Sentinel Rock, Cathedral Rocks, the hanging valley of Bridalveil Creek, and Bridalveil Fall (fig. 1). Nearby exposures of various granitic rocks and of diorite.

The abundance of joints in the diorite in the opposite valley wall (directly north of here) contrasts strongly

FIGURE 1. Some of the features seen from the east portal of Wawona Tunnel.



* Publication outharized by the Director, U.S. Geological Survey.
† For descriptions of this and other rock units in this section see paper by Calkins and Peck in this guidebook.

Photo 1. North wall of the Yosemite Valley above the Church Bowl. Light colored, nearly flat-lying dikes of coarse pegmatite and Half Dome quartz monzonite intrude Sentinel granodiorite.

Photo 2. Sentinel Cascade and its alcoves. Spalling of sheets of granodiorite around the cascade has enlarged the alcove and steepened the cliff over which the cascade plunges. Photo by U.S. National Park Service.

Photo 3. Cathedral Rocks. Light-colored dikes of Bridalveil granite intrude a maze of older granitic and dioritic rocks. Photo by U.S. National Park Service.

with their scarcity in the massive cliffs of El Capitan and the Cathedral Rocks (composed mostly of El Capitan, Bridalveil, and Taft granites, all probably of Cretaceous age). The construction in the valley between El Capitan and the Cathedral Rocks may be due to the massive nature of the granitic rocks at this point. The great abundance of talus in the cliffs directly north of here, in contrast to the paucity of talus farther up the valley, is due to the close jointing of the diorite of the cliffs.

The U-shape of Yosemite Valley, in contrast to the V-shape of the gorge of the Merced below El Portal, is well displayed here. The bottom of the U, however, is much flatter than in typical glaciated valleys. According to Gutenberg, Buwalda, and Sharp (1956, pl. 5), the bedrock surface lies almost 1,000 feet beneath the floor of the valley between El Capitan and Cathedral Rocks, and what we see is essentially a plain floored by lake sediments.

The top of the highest glacier in Yosemite Valley, according to Matthes (1930), reached about to the brow of El Capitan, and was about 300 feet above the top of the Cathedral Rocks. The glacier swept around the flank of Sentinel Dome, but did not cover the dome. The upper 700 feet of Half Dome, likewise, was unglaciated. These domes owe their form to concentric spalling of massive unjointed rock, not to glacial erosion.

The steep lower course of Bridalveil Creek above Bridalveil Fall is graded to the level established by the Merced River during the most recent of three distinct stages of preglacial erosion (from oldest to youngest, the Broad Valley, Mountain Valley, and Canyon stages of Matthes, 1930, p. 45-50); hence it helps to define the amount of glacial erosion in Yosemite Valley.

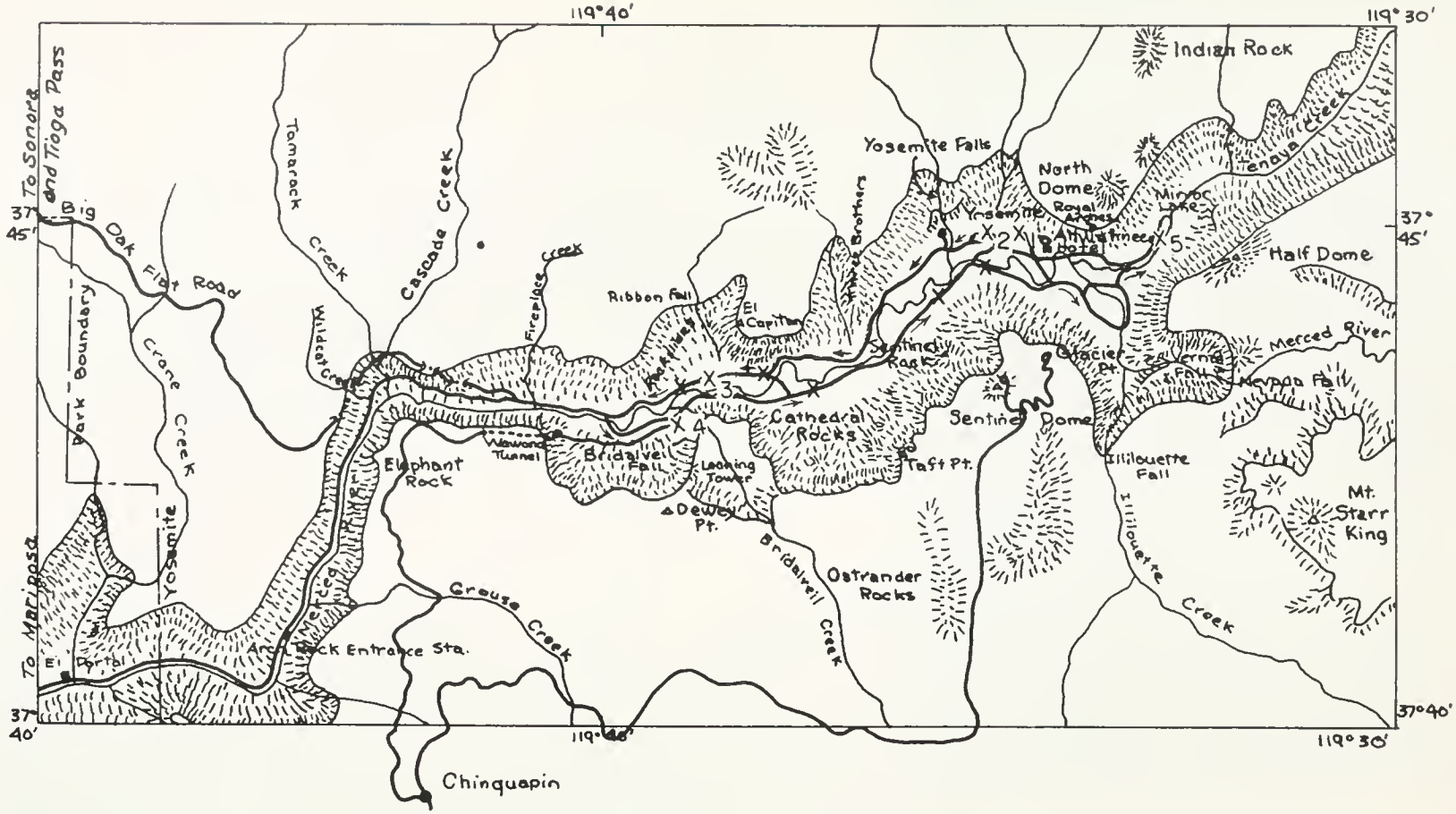
The V-shaped form of the gorge of the creek, although typical of stream erosion, is preserved because the sloping walls of the gorge coincide with throughgoing joints in the otherwise nearly unjointed rock. The upper part of Fireplace Creek, a little downstream from us on the opposite wall, is graded to the Mountain Valley stage of the Merced Canyon. Ribbon Creek, above the head of Ribbon Fall (which cannot be seen from here, but can be seen on the north wall of the canyon from places a mile or two down the road), is graded to the Broad Valley stage of the Merced (see Wahrhaftig, herein, fig. 4).

The blasted rock face at the west end of the parking lot exposes a complicated mixture of diorite and El Capitan granite. The porphyritic phase of the Taft granite is well exposed on the slope just to the west. El Capitan granite along the south side of the road contains blocks of partially assimilated diorite, and has a steeply dipping foliation.

Turn around and drive east along the south side of the Valley, across Sentinel Bridge and to the Ahwahnee Hotel.

CIRCUIT OF YOSEMITE VALLEY

Mileage	
0	Ahwahnee Hotel. The route is plotted on the sketch map of the Yosemite Valley area (fig. 2).
0.3	Entrance to Ahwahnee Hotel, turn right.
0.5	**STOP 1.** Church Bowl. View across valley of Glacier Point. In the cliff face west of Glacier Point, note the contrast between unjointed Half Dome quartz monzonite (probably Cretaceous) below, and jointed granodiorite above. In the center of the valley south of here as much as 2,000 feet of glacio-lacustrine debris overlies the bedrock (Gutenberg, Buwalda, and Sharp, 1956; see Wahrhaftig, herein, fig. 5). In talus and in cliff faces on the north side of the valley at this stop dark-colored Sentinel granodiorite is cut by gently dipping light-colored dikes of coarse pegmatite and Half Dome quartz monzonite at the margin of the large body of Half Dome quartz monzonite. In some of the dikes of quartz monzonite unequal concentration of dark minerals produces a nearly horizontal layering.
0.7	**STOP 2.** Parking lot at Yosemite National Park Headquarters. Visit to Museum.
1.7	View of Sentinel Rock across valley. Along the cascade of Sentinel Creek to the right (west) of the rock, can be seen recesses caused by spalling of the granitic rocks around the cascade. Enlargement of the recesses appears to be developing vertical waterfalls from this sloping cascade.
3.0	View of El Capitan straight ahead.



SKETCH MAP OF THE YOSEMITE VALLEY AREA, CALIFORNIA

→ Route of fieldtrip for circuit of valley

X View stop

X_2 Geologic stop

FIGURE 2

Photo 4. The Yosemite Valley from Valley View. At left is the great cliff of El Capitan, at the right the Cathedral Rocks and Bridalveil Fall. In the foreground is Bridalveil Meadow, which is underlain by almost 1,000 feet of Pleistocene glacio-lacustrine deposits. Photo by U.S. National Park Service.

Photo 5. Ribbon Fall and its alcove. The edges of cracks along which great sheets have spalled can be seen near the head of the alcove. Photo by U.S. National Park Service.

Mileage

3.9 Junction at north end of El Capitan Bridge: continue straight ahead. Brief stop for view, across valley, of Cathedral Rocks, Cathedral Spires, and Taft Point. On the faces of North and Middle Cathedral Rocks can be seen nearly horizontal light-colored dikes of Bridalveil granite cutting a maze of other granitic and dioritic rocks.

4.6 **STOP 3.** (At V-7 sign.) The low ridge to the left is the easternmost of a series of Wisconsin terminal moraines, which held in the former Lake Yosemite. The lake was filled with as much as 300 feet of silt and sand deposited in advancing deltas by the Merced River and Tenaya Creek; this debris was possibly supplied by glaciers of Tioga age, which reached only as far downstream as the lip of Nevada Fall and the upper part of Tenaya Canyon (see Wahrhaftig, herein, fig. 5). Walk south along the old road at the east side of the moraine to the Merced River, a distance of about 800 feet. In the moraine at the river are exposed boulders of Cathedral Peak granite, Half Dome quartz monzonite, Sentinel granodiorite (probably Cretaceous), and Bridalveil granite. The nearest exposure of Cathedral Peak granite is 12 miles east of here. Return to the main road and continue west.

4.9 Turnout. Brief stop for view of Bridalveil Fall, Leaning Tower, and Cathedral Rocks across valley.

5.8 Valley View turnout. Brief stop for view of El Capitan, Clouds Rest, and Sentinel Rock to the east and Cathedral Rocks and Bridalveil Fall to the southeast. The westernmost of the Wisconsin terminal moraines lies a few hundred feet west of here.

6.0 Turn left across Pohono Bridge.

6.5 View of Rockslides across valley.

6.7 Road again crosses the westernmost Wisconsin moraine.

7.0 Junction with Wawona Road; turn right.

7.1 **STOP 4.** Turn left into parking lot. Walk along trail (about 1,000 feet) to viewpoint at base of Bridalveil Fall. Near viewpoint are fallen blocks of Leaning Tower quartz monzonite (probably Cretaceous), Bridalveil granite, diorite, and El Capitan granite. On the cliff face at the lip of Bridalveil Fall can be seen a thick horizontal sheet of smooth-weathering Bridalveil granite. Underneath is reddish rough-weathering Leaning Tower quartz monzonite, and to the east is dark diorite. Note that the lower part of Bridalveil Fall is in a slight recess flanked by buttresses. The borders of the recess are marked by the edges of slabs parallel to the surface, apparently the original continuations of these slabs across the face of the fall have dropped from the cliff and are represented by the cone of talus extending up the cliff to an apex just west of the base of the fall.

Looking across the valley to the recess in which Ribbon Fall lies, one can see similar spalling in the upper part of this recess. Return to parking lot and drive east along the south side of the valley past the turnoff to Pohono Bridge. Bank on south side of road exposes bouldery terminal moraine.

7.9 Road crosses the moraine examined at Stop 3.

8.4 View of El Capitan across valley.

8.8 Junction with road to El Capitan Bridge. View of Sentinel Rock to the east, directly up the road. The forms of Sentinel Rock, Glacier Point, the north face of Half Dome, etc., are controlled by vertical joints trending east to northeast.

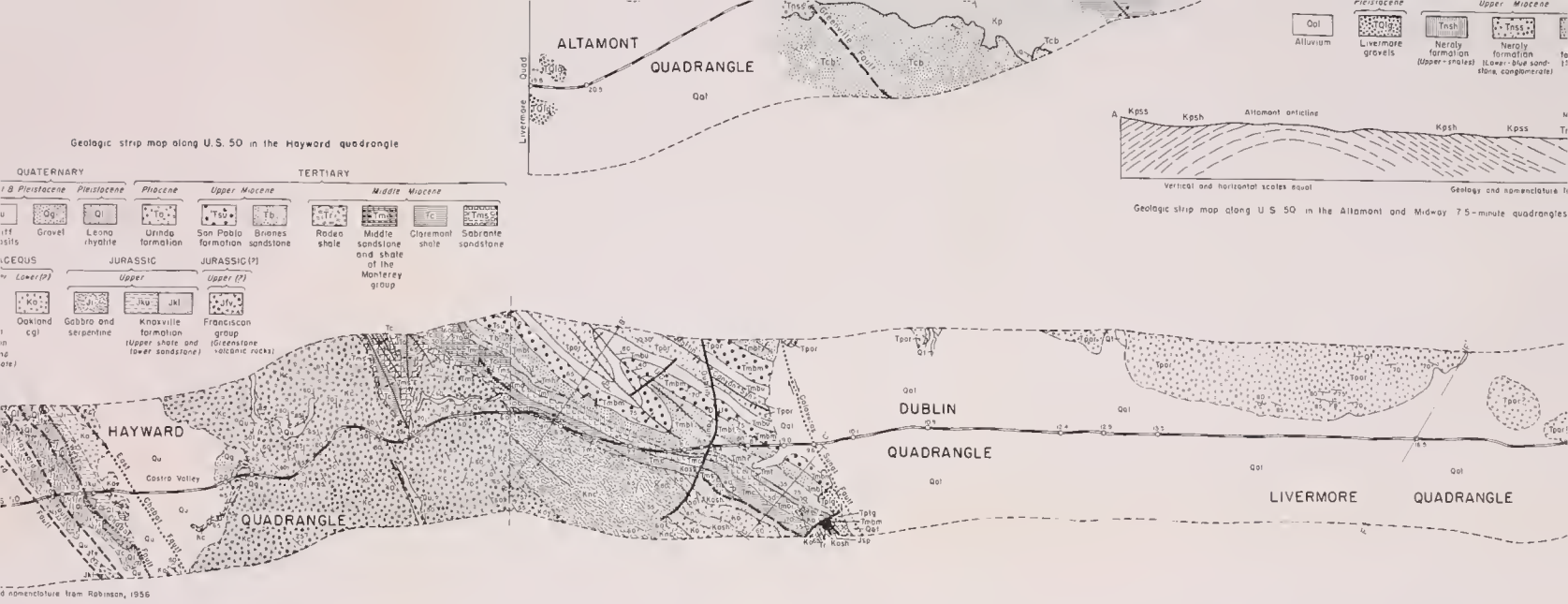
9.0 Brief stop at V-33 sign for view of El Capitan and Three Brothers across the valley. On the face of El Capitan the irregular boundaries of an intrusive body of diorite form

Photo 6. Road cut through the terminal moraine on the south side of Yosemite Valley at the base of Cathedrol Rocks. The large boulder at the right-hand end of the cut is of Cathedral Peak granite, the nearest exposure of which is 13 miles away. Photo by U.S. National Park Service.

Photo 7. Southeast face of El Capiton. The irregular boundaries of an intrusive body of diorite form a crude map of North America.

Photo 8. The Three Brothers. The west-dipping joints that give these monuments their characteristic shape are emphasized by a light fall of snow. Photo by U.S. National Park Service.

Photo 9. Half Dome from Glacier Point. The precipitous northwest face is bounded by the wall of a nearly vertical fissure. The rounded back of the dome was formed by exfoliation of massive quartz monzonite. Photo by U.S. National Park Service.



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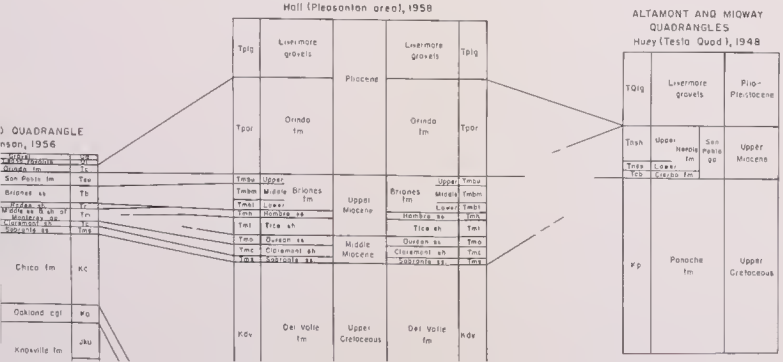
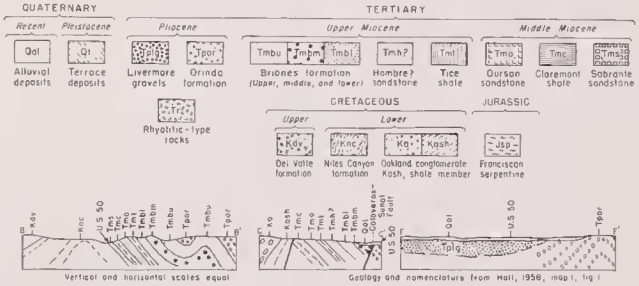
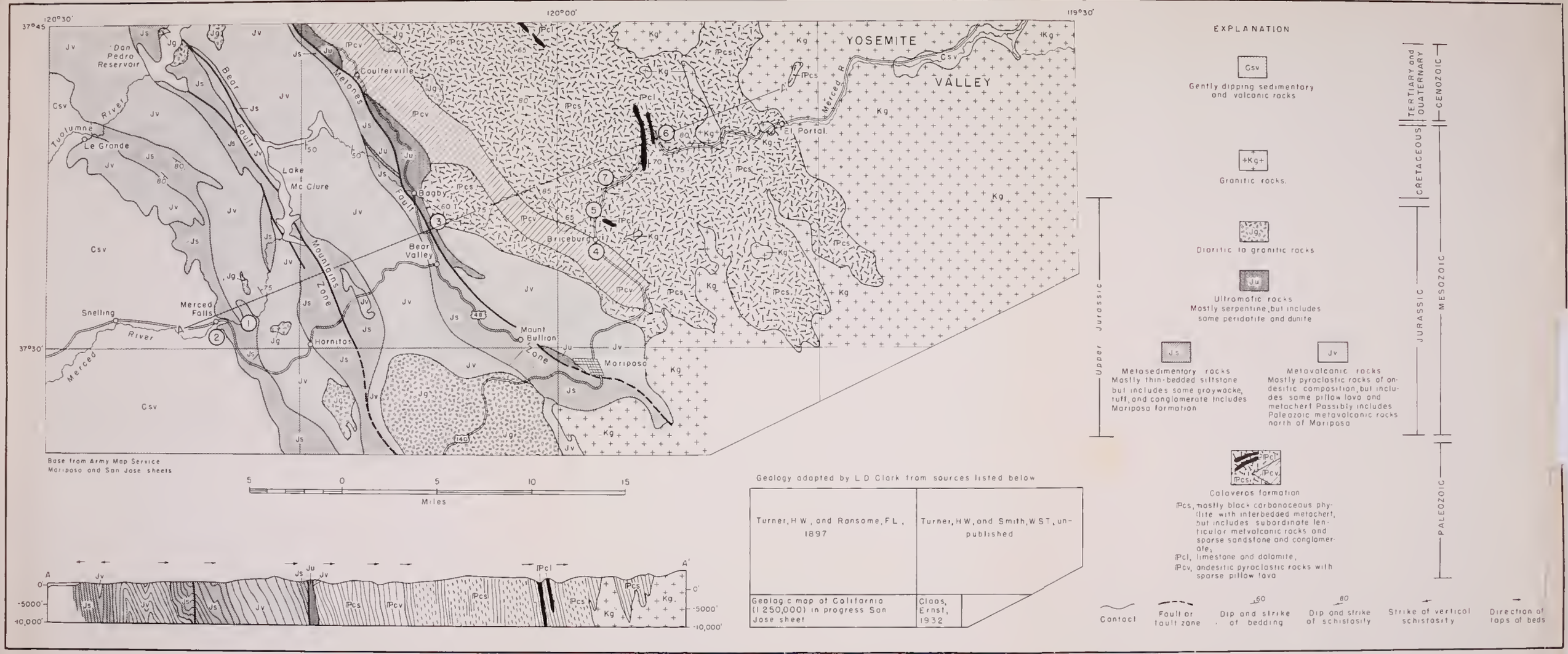




GEOLOGIC GUIDE MAPS ON HIGHWAY 50—HAYWARD TO TRACY, CALIFORNIA



Geology adapted by L D Clark from sources listed below

Turner, H W, and Ransome, F L, 1897	Turner, H W, and Smith, W S T, unpublished
Geologic map of California (1 250,000) in progress San Jose sheet	Claos, Ernst, 1932

GEOLOGIC MAP AND SECTION OF THE SOUTHERN PART OF THE WESTERN SIERRA NEVADA METAMORPHIC BELT

Photo 10. Glacial polish and slickensides on north wall of Yosemite Valley near Mirror Lake.

Mileage

a crude map of North America. This cuts an inconspicuous westward-sloping dike of gray rock, probably Leaning Tower quartz monzonite. The form of the Three Brothers is controlled by joints dipping obliquely westward.

10.6 View of Yosemite Falls across the valley.

11.1 Road junction at south end of Sentinel Bridge. Continue east, not crossing bridge. South of here are remnants of the Old Village, the center of commercial activity in the valley between the late 1850's and 1917.

11.2 Brief stop for a view to the east of North Dome, Half Dome, Royal Arches, Washington Column, and Glacier Point. The form of the Royal Arches, Half Dome, and North Dome is controlled by exfoliation of the Half Dome quartz monzonite, resulting from expansion due to unloading brought about by denudation.

11.5 Road junction; continue straight ahead.

12.2 Road crosses Happy Isles Bridge.

12.7 Road crosses Wisconsin moraine. View of North Dome straight ahead.

12.8 Road junction; bear right.

13.1 Road junction; bear right.

13.5 Road crosses rock avalanche that dammed Tenaya Creek, forming Mirror Lake.

Mileage

13.8 **STOP 5.** Parking lot at Mirror Lake. View of Mirror Lake, and of Tenaya Canyon to the east. Walk along trail to the northeast about 1,000 feet to see glacial polish and striae on Half Dome quartz monzonite. Note well-formed books of biotite in this rock.

Return to parking lot and drive west.

14.5 Road junction; bear right.

14.7 "Indian Cave," north of road, is in coarse talus at the foot of the cliff.

14.9 View ahead of sheeting in the Royal Arches, formed by exfoliation.

15.3 Sugar Pine Bridge.

15.7 Road junction; bear right.

15.8 View ahead of flat-lying dikes of Half Dome quartz monzonite and pegmatite in Sentinel granodiorite.

15.9 Entrance to Ahwahnee Hotel; turn right.

16.2 Ahwahnee Hotel.

References

Gutenberg, Beno, Buwalda, J. P., and Sharp, R. P., 1956, Seismic explorations of the floor of Yosemite Valley, California: Geol. Soc. America Bull., v. 67, p. 1051-1078.

Matthes, F. E., 1930, Geologic history of Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, 137 p.

Photo 11. The Royal Arches, North Dome, Washington Column, and Basket Dome, from near Glacier Point. These monuments are carved from a nearly joint-free mass of Half Dome quartz monzonite. Thin exfoliation slabs can be seen near the top of North Dome. The Royal Arches can be seen in this photograph to be the edges of giant exfoliation sheets formed on the southwest side of this joint-free mass. Photo by U.S. National Park Service.

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